

***EVALUATING A MULTI-CRITERIA MODEL FOR HAZARD AND RISK
ASSESSMENT IN URBAN DESIGN***

TWO VOLUMES - VOLUME 1

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The aim of this research is to test a decisional aid model - the Analytic Hierarchy Procedure (AHP) - in risk assessment for development of an urban area.

The Port Authority of Venice commissioned the Regional Environmental Protection Agency (ARPAV) to carry out an estimation of major industrial hazards in Porto Marghera, an industrial estate near Venice (Italy), via Quantitative Risk Analysis (QRA). However, this model only provided a list of individual quantitative risk values, related to single locations. Therefore, there was both a need and an opportunity to introduce a decision aid model, which could take into account the geographic distribution of risk, the quantification of intangible factors and the analysis of possible future developments.

The experimental model, through a series of trade-off comparisons, encouraged the use of expert opinions in conjunction with traditional quantitative analysis, enabling the decision maker to generate quantitative data on risk assessment from a series of subjective, qualitative assessments. It was also a major result to bring together complementary skills and expertise from different disciplines in a wide and clear collaborative research project.

The general purpose of this research is to develop a framework model to be used whenever an industrial risk scenario must be assessed or/and future risk scenarios predicted, within the context of major environmental issues.

The control of major industrial hazards and the prevention and mitigation of major industrial accidents is a foremost need resulting from the experiences of the past few decades. Recently, the European Authorities have produced many different directives and regulations to assess and minimise the likelihood of significant accidents in areas where hazardous plants are located. In particular, the last directive proposes increasing the participation of operators, taking the other players into account; moreover, paying more attention to the concepts of 'urban control', 'subjective risk' (risk perception) and intangibility. However, the standard procedure for risk assessment is not suitable for this kind of analyses. In addition, it provides a list of individual quantitative risk values, related to single locations, only. Therefore there is both a need and an opportunity to introduce a new methodology, which could take into account all these factors. It should be a valid aid for avoiding environmental problems and interest conflicts in planning procedures.

The real opportunity for developing and testing a model arose from the need of the Venice Port Authority to provide a Safety Report, in line with the last directive requirements, for Porto Marghera, an industrial estate close to Venice. This authority charged the Italian regional Environmental Protection Agency ('ARPAV') to undertake the appropriate analyses, including an experimental evaluation. This experimental analysis was aimed at generating quantitative data on risk assessment from a series of expert opinions, to be used in conjunction with quantitative traditional analysis. This data concerned the present situation and other three possible development scenarios of the industrial estate.

Initially, the problem of major industrial hazards was studied in relation to the most important regulations and most common assessment techniques. Therefore, the standard procedure, which is the Quantitative Risk Analysis (QRA), was carefully analysed. Its advantages and disadvantages were identified. In particular the following are the most important limitations:

- 1) it does not take into consideration intangible factors (in detail: general population and type of accidents and plants, geographical distribution of risk)
- 2) it does not provide any overall judgement on the risk status of the industrial estate,
- 3) it does not take into consideration the 'subjective' judgement on risk.

The first and the second criticisms, in particular, make the procedure inappropriate for assessing very complex estates and for making any inference on future developments.

A study of a more appropriate methodology for implementing the procedure was carried out. It led to the use of multi-criteria techniques, in particular the Analytic Hierarchy Procedure (AHP). In fact, Multi Criteria Models are techniques which allow to measure and aggregated the performances of one or more options with respect to a variety of both qualitative and quantitative factors (criteria) into a unique value. The Analytic Hierarchy Process, elaborated by Thomas Saaty in the early '70, is a very simple multi-criteria model. In detail, it is based on three main features:

- 1) A hierarchy, which orders the elements in a structure (main goal → factors → scenarios).
- 2) A trade-off comparison technique for determining the relative importance of each element of the hierarchy. It is in the simple form of a question type: 'how much more significant (or preferred) is element A compared to element B, with respect to some factor?'

3) The Saaty scale, which is a five-point scale. It is used in the pair-wise comparison phase for determining the importance of each element in the form of both verbal and numerical judgements.

The relative importance of the elements are then aggregated into a unique value by using a mathematical model, so that the higher the score, the greater the efficacy of the option. The AHP model has been selected because of its main features:

- its flexibility (it can deal with both qualitative and quantitative data);
- its simplicity (data are gathered through a series of trade-off comparisons);
- its similarity with the standard procedure (both the models use a hierarchy for ordering the elements of the problem).

The case study location is a wide trapezium shaped industrial area (about 2,000 hectares), located between the outskirts of Marghera and the Venice Lagoon. It is recognised as being an important traffic crossroads, providing the central and eastern countries in Europe with easy access to the sea. The area embraces the industrial estate proper, 1,400 hectares wide, the commercial harbour (120 hectares) plus canals and basins (340 hectares), part of the Venice Lagoon, and the inner traffic and railway network (80 hectares). At present, there are 295 firms, with 13,740 employees. The most important activities are:

- 1) chemical production and treatment,
- 2) petrochemical industries,
- 3) crude oil storage and deposits,
- 4) ironworks and steel industries (shipyards, especially),

However, it suffers from many different problems, mainly due to: the type of hazardous industries still working; the presence of inner space available for different uses;

the closeness of many residential areas as well as important monuments; the lagoon, which is constantly under the threat of an ecological disaster.

As already mentioned, the Italian Environmental Protection Agency carried out a traditional hazard assessment of the estate based on 256 accident scenarios provided by the industry conductors. The Agency computed and plotted on maps:

- zones of possible damage (injury and fatality) due to different events (toxic gas release and fire/explosion) in the forms of circular areas;
- frequency of accidents, distinguished by type of possible damage and event, in the form of a grid.

In general, the toxic injury scenarios presented larger areas. This kind of information was found to be significant in terms of political and social management by the local and central authorities. Therefore, it has been adopted to work out the hierarchy of the experimental model and the involved parties have been requested to express their opinion on this basis.

In order to make the experimental procedure more manageable, the area has been divided into six wide zones according to main land use and geographic feature. This division was studied in accordance with the ARPAV staff and the three experts. Similarly, the three future developments are described in terms of the six zones. These scenarios are:

- 1) the New Master Plan, which is basically an urban program aimed at rehabilitating the area economically, primarily by strengthening the existing commercial activities;
- 2) the General Agreement on chemical Hazard Mitigation Actions. This is a type of short and long term risk reduction program proposed by a general co-ordinating committee mainly composed of representatives of industrialists, with the contribution of the Minister of the Environment and all the regional and local authorities.
- 3) A composite scenario resulting from the potential conjoint occurrence of the two previous ones. In reality, it is the most probable scenario.

These scenarios, along with the present situation, were placed at the bottom of the experimental hierarchy. The main goal at the top of the hierarchy - 'to control and reduce the global hazard' - resulted from the aggregation of the risk of the six considered zones (second level of the hierarchy). Each risk was then measured in terms of injury and fatality (third level) due to the type of accidents and the type of populations (fourth level). Again, accidents were analysed relative to plants and transportation means (fifth level). In line with this scheme, the four scenarios were assessed according to the number and significance of plants/transportation means and that of the people they located in each zone.

The Judgements were gathered mainly from the involved parties by using a questionnaire, which, approximately, reflected the hierarchy. The questionnaire technique was chosen because it is a practical tool for preference surveying, which is strongly recommended by Saaty in the case of a plurality of judgements. This questionnaire was handed to representatives of the following involved parties:

- 1) the District Council,
- 2) the industrialists,
- 3) the Port Authority

However, no response came from the District Council during the preliminary arrangement. Therefore, the questionnaire was handed to an independent expert, an architect who had carefully studied the Porto Marghera Master Plan. The residents were not directly involved in order to avoid them giving an opinion on themselves.

Seven sets of results were obtained. Respectively, three from the three experts; a composite set of priorities derived from the geometric means of the players' judgements and three sets obtained from a sensitivity analysis. Sensitivity analysis is a technique for testing outcome of a multi criteria model, by introducing changes in weights, criteria priorities or aggregating functions. In this sensitivity analysis, new weights were introduced into the three

experts' assessments. These weights were derived by a survey – entitled 'Report on Risk Information Survey Concerning Marghera Residents' – conducted by the Italian EPA and providing useful information on people's perception of risk. Results were presented in forms of bar charts representing the global risk rate of the present situation and the risk improvements of the other three scenarios (partial results show how much each factor affected the global risk rate). Generally speaking, all the charts indicate that the composite scenario and the General Agreement on chemical Hazard Mitigation Actions are the most efficient scenarios. Qualitatively, much of the global risk derives from the inner areas where most of the chemicals are; while, the most important factors appear to be the risk of injury due to toxic gas emission and the number of people present in each zone.

The second section demonstrates that the new model obeys the most common economics rules. In fact, in the initial stage, the experts were asked to express their 'preferences' on five main variables (population and plants and transportation means) and to indicate trade off values of seven independent variables (type of incident, of consequences and location of occurrence), which affect the main ones. In Economics, this technique is known as 'revealed preference' and it is an empirical utility theory based on partial information on 'consumer's taste'. This allowed drawing some considerations on trade-off values and, in the case of the seven factors at the bottom of the hierarchy, building up utility functions. These functions can be used to describe the expert's behaviour facing any variation of one or a combination of factors. In general, they showed that the utility does not rise linearly according to the variable increases, i.e. a large increment corresponds to a larger satisfaction than a small one does. The resulting shape of the curve also provided an indication of the 'risk aversion' of the experts: in fact, in economics, a concave curve indicates the consumer's propensity to consume the variables.

As each scenario is a combination of all these factors, the expert's behaviour was also studied related to many variables, not only one at a time. A new utility function, given by multiplying the utilities of two variables at a time, was computed. It resulted in a 3-dimensional cone-shaped surface. Any horizontal plane cutting this surface generates a curve composed of points with the same utility value but different variable intensities (also known as 'indifference curve'). The analysis of any combination of two variables, as well as their indifference curve, could help the planner in establishing whether a future scenario satisfies the minimum utility value, e.g. the commonly accepted risk level. In fact, if the two variables:

- 1) fall within the area enclosed by the indifference curves, the utility of the scenario is surely higher than the standard (commonly accepted) threshold;
- 2) fall on the curve, regardless of the exact position, the utility of the scenario is equal to the minimum utility value (threshold);
- 3) fall outside the curves and the enclosed area, the scenario does not satisfy the commonly accepted risk level

This analytical technique introduces flexibility within the procedure for scenario assessing, in particular when dealing with potential future developments which involve different stakeholders and criteria.

In addition, a procedure for aggregating preferences of the many involved parties was presented. In economics, an effective technique is that based on the classic utilitarian welfare function and presents a general form, wherein each utility value is associated to a weight measuring the relative importance of that social group (or individual) relative to the others. It is interesting to note the similarity of this concept to the multi criteria theory.

Finally, the validity of this procedure was demonstrated by using a very simple and traditional statistical test: the 'confidence limits'. Confidence limits are boundaries delimiting

an interval of values of a statistical distribution of data where the mean is usually 95% likely to fall. Firstly, a sample of 28 people was asked to fill in the questionnaire on the Major Industrial Hazards; then, the same sample was asked to rate the same hazards directly by using a one hundred point scale. Once the two distributions of the responses were plotted, the mean values were compared to the confidence limits. The computation of these limits showed that the mean values of the first sample (the experimental sample) fell within the confidence limits of the second and, therefore, the validity of the model was practically demonstrated. Furthermore, by comparing the standard deviations of the two sets (a kind of a measure of the dispersion of data), it was noted that the former were smaller than the latter, which means that data of the first set was less scattered and, therefore, the distributions more accurate. In other words, the new methodology seemed to be more efficient, in terms of preference surveying.

In conclusion, the AHP model applied to the Quantitative Risk Analysis appears to be a valid aid to the environmental agency for measuring the environmental compatibility of any development scenario with regard to all the state components. Furthermore, if implemented by the study of utility functions and indifference curves, it is a useful tool for regional planning.

i Preface

The control of major industrial hazards and the prevention and mitigation of major industrial accidents, is a foremost need resulting from the experiences of the few past decades (Bhopal in India and Seveso in Italy are just two tragic examples of the lack of prevention) and which is increasing in importance. Bhopal – with about 800,000 inhabitants - is an industrial city in central India and was the site of a major industrial disaster in 1984. Forty tonnes of methyl isocyanides, used for the production of pesticides, leaked from a chemical plant tank killing about 2,500 people by direct exposure to the gas. In addition, more than 200,000 inhabitants suffered many health complications like respiratory problems, temporary blindness, and severe vomiting. Seveso, from which the name of the European Directive was taken (see later), is a small town in Northern Italy, close to Milan – a densely populated part of Padana valley – where, in 1976, a wide area (several hectares of territory) was contaminated by ‘tetrachlorinedibenzodioxin’, also known as dioxin, released by a chemical plant. One hundred and seventy five people were seriously injured (including children from a nearby school) and more than 200 families were evacuated. The dioxin caused fatalities among many animals and the TCDD (the scientific acronym for ‘tetrachlorinedibenzodioxin’) contaminated the alimentary chain of the region. These facts caused the European Authorities to produce many different directives and regulations on relevant hazard chemical plants, among which the most important is the ‘Seveso’ regulation – mentioned above – recently updated with an integration (‘Seveso II’)¹. The main objectives of these regulations are to assess and minimise the likelihood of significant accidents in areas

¹ Directives no. 82/501 and 96/82/CE, acquired as Italian regulation in 1988 (regulation no. 175) and in 1999 (regulation no. 334) respectively.

where hazardous plants are possible. However, the Seveso II Directive is just a transitional step in an articulated and on-going process, which must lead to safer industrial and environmental control.

The Italian territory is one of the most populated in Europe and industrial and urban expansion have been the least regulated in the last decades, in terms of environment and health control. Since the Second World War, the local authorities have shown little interest in industrial pollution control and in preventive national health measures. A consequence of this tendency is the contiguity of hazardous industrial estates and residential areas. In particular, it must be noted that the urban planning in Italy has been subordinated to economic interests. At the present, when the need for major control measures and prevention and mitigation action arises, traditional planning tools are no longer effective in this country. Urban planning and natural resources management need a wider approach, which can involve both space and time without restriction (i.e. considering the concept of sustainability) and many different players.

Along with these issues, another problem has arisen in the few past years in Europe, mainly because of the general changes in economic trends: the dismissal of many industrial settlements and the consequent abandonment of lands, which have been degrading progressively. Examples are the Ruhr region in Germany, the petro-chemical settlement in Napoli (Bagnoli) and many mining sites in Great Britain. According to many studies (L. Fusco e P. Nijkamp (1997), F. Candian (1998/99), T. Pugliese (1991)), the causes of the dismissal could be:

- The de-centralising of many different plants,
- The general reduction of production,
- The crisis of some industrial sectors,
- A substantial change of worker situation (in particular in terms of cost),

- The individuation of different economic markets.

The consequent openings are now available for different uses, including a public one.

However, the rehabilitation of disused areas is a very complex task for two main reasons:

- 1) despite lands not necessarily being contaminated by dangerous substances, they need to undergo a complex reclamation procedure.
- 2) These areas are often contiguous to – or within – active industrial estates.

Urban planning and programming of this space typology involves new aspects and the study of new regulations in order to make them safer, particularly where chemicals and other very dangerous activities are in the vicinity.

Recently, in Italy the problem of derelict industrial lands has been considered as a potentiality, in line with the general European trend. Again, the Ruhr in Germany is considered an example by Italian politicians: the industrial region has been turned into a natural area with ponds and public parks².

In a similar context, the Venice district, a very industrialised area in Northern Italy, has been the object of politicians', industrialists' and environmentalists' interests since 1980. They have looked at it as a potential place for putting into practice similar strategies. In fact, the Venice lagoon is characterised by the co-presence of:

- environmental components with aesthetic and ecological values, such as the lagoon itself;
- historical/architectonical areas such as the town of Venice and the other islands around it;
- important national and international infrastructures such as the international airport, the highways and railways going to Milano, Torino, Bologna, Trieste and also to France, Austria, Germany, and Eastern European nations;

² In reality, the procedure is still in progress.

- the district of Porto Marghera, one of the most important industrial sites in Italy and in central Europe as well.

The Porto Marghera estate is a wide trapezium shaped area (about 2,000 hectares), located between the outskirts of Marghera and the Venice Lagoon, at the end of the bridge connecting Venice to the mainland, and, therefore, very close to the town. As in many other estates, in the past few decades, its industries were subjected to a general decline, which led to the cessation of the activity of larger plants and the introduction of new non-industrial activities within the area. As a result, the estate suffers from many different problems, mainly due to: the type of hazardous industries still working and the presence of space available for different uses; the closeness of many residential areas as well as important monuments; the lagoon, which is constantly under threat of an ecological disaster.

There have been many previous attempts of the Veneto Region local authority to rehabilitate the space of Porto Marghera. However, they partially failed as the dimension of this area is so wide as to require a proper political program, which also involves the national authority. At the time of writing, a strict collaboration between local and national authorities has been set and this political program is now operating (the 'General Agreement on Chemical Hazard Mitigation Actions' is an example which is illustrated in the next sections). According to the above-mentioned considerations, Porto Marghera can be considered as a national pilot project of industrial estate restoration programme.

The real opportunity of developing and testing a model arises from the need of the Venice Port Authority to provide a Safety Report for the industrial area of Porto Marghera, in line with the "Seveso II" directive requirements, which regard chemical plants and transportation means as dangerous to both human beings and the environment (see the 'Regulations' section). This authority charged the Italian regional Environmental Protection Agency ('ARPAV') to undertake the appropriate analyses, including an experimental Multi-

criteria evaluation, which is the main subject of this thesis. According to the national regulations and the most common scientific literature, the main purpose of the EPA study can be expressed by the following chart actions (Safety Report, page 9):

To understand → to prevent → to forecast → to mitigate.

However, the Safety Report and the Italian EPA studies do not particularly focus on mitigation, rather on the other three stages. In particular, the EPA analysis mainly concerns the understanding phase (Societal Risk, F-N curves, and many other concepts explained in the 'QUANTITATIVE RISK ASSESSMENT' section), while the Safety Report represents the prevention stage. Furthermore, these analyses do not consider intangible factors (in detail: general population and typology of accidents and plants, geographical distribution of risk) the 'subjective' judgement on risk. and the geographical distribution of hazards.

Taking these ideas into account, this research initially aimed at defining and computing an overall risk rate and the appropriate calculation procedure based on multi-criteria analysis and expert opinions. Further improvements arose from the opportunities to include development scenarios, in order to embrace the "forecasting" stage within the study, too. In fact, the Safety Report states that planning and programming, in terms of safety measures, should also describe and compute industrial hazard rates in order to assess and manage any complex industrial structures considering both present and future situations (Safety Report, page 17). In particular, three scenarios have been identified and studied for this purpose, as they reflect the most important and probable outlooks for this area in terms of variation of industries and population. They are:

- A General Agreement on Chemical Hazard Mitigation Actions, which considers variation in Porto Marghera industries;

- A New Master Plan, which mainly regards variation in population of the district;
- A composite scenario resulting from the simultaneous occurrence of the two previous circumstances: variations in terms of both industries and population.

Thus, the general purpose of this research is to develop a framework model to be used whenever an industrial risk scenario must be assessed and/or future risk scenarios predicted, within the context of major environmental issues. It should be a valid aid for avoiding environmental problems and interest conflicts in planning procedures. In particular, the contribution of this study to industrial hazard assessment should result in an implementation of the standard procedure (the Quantitative Risk Analysis) with a more general technique, which allows intangibility, risk perception and geographic distribution of risk to be taken into account, providing a measure of environmental compatibility of the area with respect to all the environmental components, human activities and pollution sources.

The study of a framework model based on multi-criteria analysis and expert opinions can be seen as a minor contribution to safety and security in the industrial planning process and is open to criticism. However, this research has been recently encouraged by the fact that the European Institute of the E U Joint Research Centre in Ispra (Varese, Italy) is now studying a similar model for industrial hazard assessment. The Research unit, indicated as 'Risk Management and Decision Support', aims at contributing to the safety, security and trustworthiness of technological and societal systems by developing innovative methods, tools and strategies for the assessment and management of risk and uncertainty and for supporting decision making processes. This unit is also developing some specific projects on related issues such as: techniques for facilitating dialogue and participation of a wide variety of stake-holders in environmental decision-making (including multi-criteria tools), models

for implementing and monitoring Community policy on the control of major hazards and preventing and mitigating major accidents related to chemical plants³.

The reader might be also interested to know that results from the study case analysis have been handed to the Port Authority as part of the Official Safety Report and the framework model (including software developed for this purpose) has been acquired by the Italian regional EPA as part of its tools for risk assessment (see letter in annex 5). From this point of view, this cooperation has been recognised as capable of developing a new approach, which encourages the use of expert opinions in conjunction with quantitative traditional analysis. It is also a major result to bring together complementary skills and expertise from different disciplines (and, possibly, organisations,) in a broad and clear collaborative research project.

ii. Work structure

The structure of the work follows a simple order:

- 1) Initially, a real world problem is observed and analysed;
- 2) The deficiency of the 'state of art' model is highlighted along with opportunities for improvements;
- 3) A newer alternative approach is presented (the improvements) and tested practically;
- 4) then, a specific traditional test is performed in order to validate this approach.

However, the present thesis has been divided into two main, wide-ranging parts ('section one' and 'section two'), which principally regard:

- experimental application description (phases one to three),
- model and results analyses (phase four plus appendices).

This distinction corresponds to a difference in time, i.e. the first part concerns the practical application of the model to the study case area, which had a milestone corresponding to the

³ More information on these researches can be found in the ISPRA web site: www.jrc.it

deadline for handing results to the Venice Port Authority to be included in the annex to the ‘Safety Report’⁴. At a later stage, all the analyses and considerations on the procedure were elaborated and gathered into the second part.

A detailed description of the work is presented below.

After general explanation on the main Italian regulations on chemical hazards, the first section introduces the procedure and explains its needs and the choice of the multi criteria model (*Introduction to standard quantitative risk assessment* and *The procedure: an overview*). Then, the common procedure for quantifying chemical hazard risks is explained in detail along with the most important indices and measures (*The risk indices, The individual risk, The societal risk*) and their representation. At this point, the multi criteria analysis is introduced in general (*Environmental evaluation methods* is an historical review) and the Analytic Hierarchy Process (AHP) procedure, in particular, is illustrated (*The multi criteria analytic model AHP*), which is the multi criteria model adopted in this work. The case study area, the particular problem and potentialities are fully described in an appropriate section (APPROACHING THE PROBLEM). The section devoted to the application (APPLYING THE EXPERIMENTAL ANALYTIC FRAMEWORK MODEL) includes: the description of the scenarios, the Italian EPA’s results from its analyses, the description of the experimental procedure and the questionnaire used to collect experts’ opinions. Results are analysed into a separate section (RESULTS EVALUATION). They are distinguished according to the respondents, and then aggregated in a unique set of results (*Combined priorities: the geometric mean technique*). In addition, a sensitivity analysis is performed (*The sensitivity analysis on integrated data and Outcomes from integrated data analysis*).

Notes on results and recommendations conclude the first part. Section two analyses the experts’ behaviour by using economics concepts (THE EXPERTS’ BEHAVIOUR): first

⁴ As already mentioned, this research is included in the ‘Safety Report’ as annex.

the concept of revealed preferences is introduced, then variables are defined. At the end, indifference curves are discussed in order to introduce the paragraph THE GLOBAL PREFERENCES where an aggregating function is described. An appendix to this chapter explains the concepts of ‘expected utility’ and ‘cost of risk’. The last section illustrates a statistical test, which has been used to validate the experimental procedure: it is a type of qualitative confidence limits analysis. A useful glossary can be found at the end of this report, along with the bibliography and a list of annexes which include the questionnaire, a table of results, the evaluation resume charts (original copies of those handed to the Port Authority) and the software (which has been used to compute the indifference curves), as well as options for a more rigorous ‘T’ test for confidence limits.

SECTION ONE

1. MAJOR ACCIDENT HAZARD CONTROL

1.1. Regulations on Major Accident Hazard control and prevention

Many European and Italian regulations on Major Accident Hazard¹ regard different contexts, such as industries, agriculture, services, and pollution in general (atmospheric emission, domestic waste, industrial toxic waste, etc.). The already mentioned “Seveso” Directive— no. 82/501 – specifically on Major Accident Hazard of Certain Industrial Activities (Chemicals), was approved by the European Community in consequence of the tragic accident in Italy in 1976². The Italian Government adopted this directive as a national regulation in May 1988 – decree no. 175 of the President of the Italian Republic, which was amended and improved several times until 1997, when a new updated regulation was definitely approved: national law no. 137. In the meantime, the European Community also amended the Directive no. 82/501, producing a second directive – Directive no. 96/82, also known as “Seveso II”, which was recently adopted by the Italian Government again as a decree. This last regulation is not very different from the former as both of them regard quantity limits of chemical hazard substances for industrial production activities, regardless of potential prevention and protection measures. The difference between the two is in the fact that the first concerns a list of dangerous production activities only, while the second includes also deposits, single plants, etc. Therefore, the presence of only one dangerous plant

¹ A common definition of Major Hazard accident is: any event, which comports release of material and/or energy. In fact, it takes into account the fact that usually dangerous substances are kept in special containers. Therefore, examples of non-controlled release of material can be: dangerous liquid leakage and gas emission; whereas, fire of a container or its explosion are examples of energy emission.

² In 1976, a leakage of dioxin from a plant of a chemical industry for producing pesticides – Icmesa – produced serious injuries to persons – more than 175 people were hospitalised, 200 families evacuated – and problems to the environment, in the small town of Seveso, Northern Italy.

– which is listed in the Italian regulation – within the industrial precinct, would make the entire industry become a potential source for major industrial accident. The most relevant Italian regulations are listed in Appendix A.

DPR (Decree of the President of the Italian Republic) no. 175/88 and Regulation no. 137/97 are the most important legislative references for this work. The first regulation obliges those responsible for major accident hazardous industries to assess accident risks and present results to the appropriate authority regularly.

Typologies of plants, which must be assessed according to the regulation, are:

- Plants for production and treatment of organic and non-organic chemical substances.
- Distilleries, refineries and similar plants, which treat crude oil and its derivatives.
- Plants for combustion and chemical treatment of both liquid and solid refuse.
- Gas production and treatment plants.
- Coal and lignite treatment plants.
- Metallurgical plants.

As mentioned above, these typologies refer to a list of hazardous substances and related quantity thresholds, which can be found in an attachment to the decree and in the subsequent circulars. A classification of the industrial petrol-chemical activities is based on these quantity threshold classes: class activity A, B and C. The first two require a Safety Report and an official notification (class A) or a declaration (class B) to the local and Central Authorities. For Class B, the Safety Report is then divided into two sub-categories (B1 and B2) according to the kind of accident assessment and relative consequences. In this case, headings and contents of the Report are strictly indicated by annexes to the decree DPR 175/88 and DPCM 31/03/89. Activities included in category C are not requested to present any declaration as the quantity of the hazardous substances does not exceed the standard threshold indicated in the afore mentioned decree appendix and circular.

The legislative decree no. 334 17/08/99, in line with the European Directive 96/82, replaces and updates DPR no. 175/88 and Law no. 137/97. Three major innovations are introduced by this new regulation:

- 1) The conductors are requested to prepare and adopt an industrial accident prevention policy and program.
- 2) In evaluating the Major Accident Hazard, the 'domino' effect must be taken into account, which considers the likelihood of an accident chain process among adjacent plants, in the case of only one's initial event.
- 3) Article no. 14 of the new decree, introduces also new regulations on urban planning and control of areas dedicated to industrial uses or close to industries (table 1).

This article regulates distances between residential areas, infrastructures and the industries. In addition, it explicitly considers the possibility of risk variations in case of any land use modification of non-industrial adjacent areas (i.e. variation of population).

<i>Type of hazard substance treated by the plant</i>	<i>Minimum distance (according to the quantity)</i>	<i>Maximum distance (according to the quantity)</i>
Liquid inflammable pressurised gas, at risk of explosion	m. 600	m. 1000
Liquid inflammable gas, refrigerated	m. 400	m. 600
Liquid inflammable (or easily inflammable) gas	m. 200	m. 400
Toxic (or very toxic) gas or pressurised liquid	m. 2000	m. 4000
Toxic (or very toxic) refrigerated liquid	m. 1500	m. 2500
Liquid toxic (or very toxic) substances	m. 1000	m. 2000
Inflammable solid substances (or liquid kept in drums) which can let off toxic vapours	m. 500	m. 1000

Table 1: safety distances introduced by article no. 14, decree no. 334 17/08/99.

1.2. Introduction to Major Accident Hazard assessment

According to the Italian regulation, the new planning proposal for Venice Industrial Harbour area, named Porto Marghera, should have an accompanying report concerning industrial accidents assessment and safety measures. The Port Authority of Venice has commissioned the Regional Authority for Environmental Protection (ARPAV) – Italian regional EPA - to carry out this assessment and to experiment a Decision Aid model procedure to evaluate the efficacy of the safety measures and of two new development proposals for the area, as already stated in the introduction (see also ‘Regulations’ section).

Due to the complexity of the problem, the ARPAV experts proposed the following simplifications: 1) the number of parties involved should be limited to four; 2) the new proposals were evaluated in line with a single goal (risk reduction); 3) many intangible factors were quantified. In line with the Italian EPA’s initial idea (see the EPA’s letter in Annex 5), the ARPAV proposed the procedure should constitute a valid aid to the decision maker. The following chapter is devoted to illustrating the standard procedure for risk and hazard assessment in any industrial contexts. The difference between these two concepts – risk and hazard – is in the fact that the first is a measure of damage, while the second is referred to any condition, which has the potential to cause damage.

2. QUANTITATIVE RISK ASSESSMENT

2.1. *The procedure: an overview*

Risk may be classified on the base of its causes: natural (catastrophes, etc.) or human. The latter may be due to working activities or to other human actions - for example, recreational ones - which, indeed, are the most frequent occasions of human fatality. However, the likelihood of a tragic event is generally accepted as the counterpart of the inexorable improvement in standards of life as well as technology, under the condition that this likelihood does not exceed a reasonable and commonly recognised hazard limit. Therefore, the problem is to quantify this risk. It is not by chance that almost every definition of risk implies the combination of probability and uncertainty. These definitions and the relative terminology are so numerous that the reader may be led to confusion (G. F. Clemente 1994, F. Ippolito 1994, P. Miani 1994, K. S. Shrader-Frechette 1993); however, in this research, and according to the most important studies listed in bibliography (ANPA 1998, AAVV 1996, F. Candian 1998/99), 'risk' is identified as a combination of the consequences of one or more hypothetical accident scenarios and of the expected frequencies of occurrence. The risk measurement procedure is also not unique as it depends on the initial information, the available resources and the use of the final results. In general, it is possible to distinguish among three different techniques of combining the above-mentioned parameters: the risk indices, the individual risk and the societal risk. Before describing them, the reader must be aware that, due to the nature of the matter (uncertainty, subjectivity, intangible), the models for risk estimation suffer from different grades of approximation.

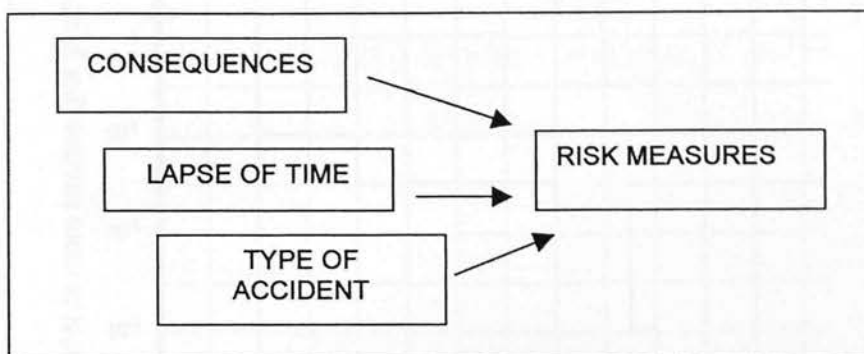


Figure 1: main inputs for risk measuring

As already mentioned, the general risk analysis of Porto Marghera Estate has for the purpose of this research been divided into two different phases: quantification of local risk rate by the standard procedure and application of the AHP model. In the former, the Environmental Authority computed the local risk rate of significant potential accidents. This quantification is based on the idea that some particular circumstances (human mistake, equipment deterioration, etc.) can regularly generate events (irregular functions, failures, etc.). These events may cause one or more accidents. Therefore, given the number and type of hazardous industrial plants and transportation means, and statistical data on these events, it is possible to determine the accident likelihood and frequency in a lapse of time. Usually, frequency – which is the most relevant information - is related to a standard injury, so that the data is provided as a ratio $F-N$ - where F is frequency of accident causing N number of events - in a table, a chart or graphically as a contour connecting points with the same $F-N$ values (see figure 2 and 3). Usually, frequency is expressed in the form of orders of magnitude and measured on a logarithmic scale, while events may be referred to a standard number of fatalities or injuries. For example, “ 10^{-2} per 100 fatalities” (also expressed as E-02) means that an accident killing one hundred of people occurs every 100 years.

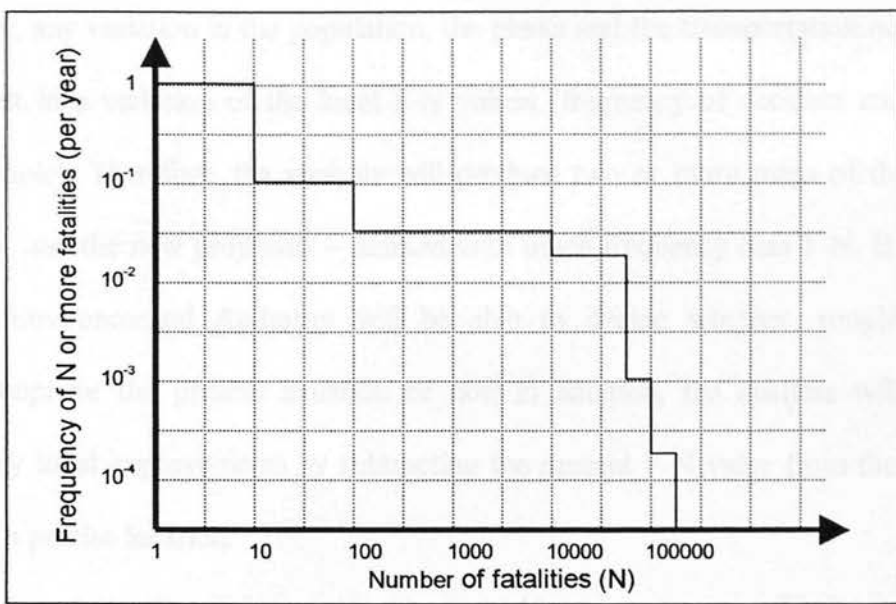


Figure 2: an example of F-N graph presenting the risk of different group sizes of people affected. This information regards one precise geographical location only.

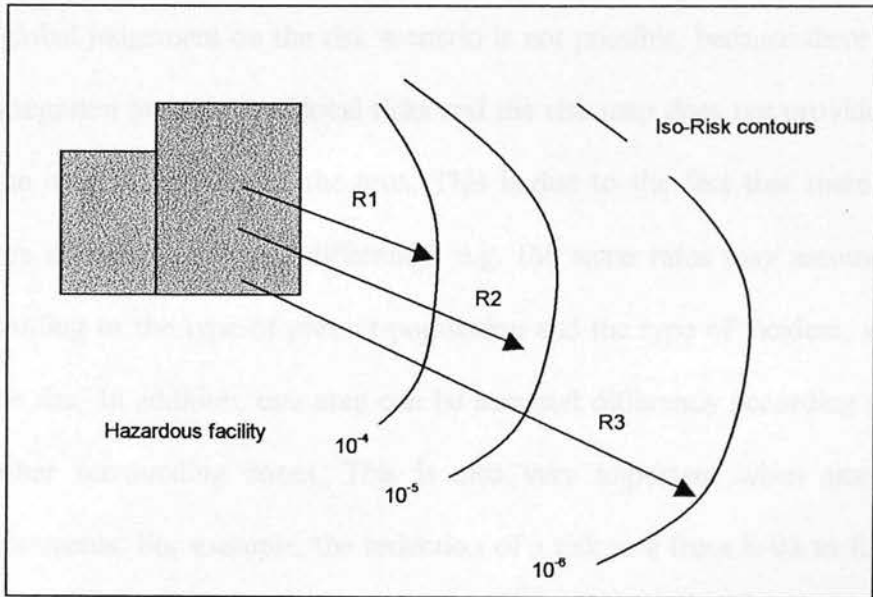


Figure 3: an example of risk contours (AAVV 1996). A contour map is a method for presenting the geographical distribution of Risk: R is distances from the hazardous facility, while 10^{-n} are event frequencies expressed in logarithmic form. These events may be referred to a standard number of fatalities or injuries.

Accordingly, any variation in the population, the plants and the transportation net in the area would result in a variation of the local F-N values (frequency of accident and number of affected people). Therefore, the analysts will produce two or more maps of the area – the ‘status quo’ and the new proposals – marked with much frequency data F-N. By comparing them, the Environmental Authority will be able to decide whether, roughly, the new proposals improve the present situation or not; in addition, the analysts will be able to compute any local improvements by subtracting the present F-N value from the future ones concerning a precise location.

At first sight, the reader could object, thinking that the use of a Decision Support System is superfluous in such a context as the geographical distribution of risk of the present situation and that of any other urban scenarios can be computed and plotted on a map. However, any global judgement on the risk scenario is not possible, because there is not any quantitative aggregation procedure of local risks and the risk map does not provide any valid indication on the overall risk rate of the area. This is due to the fact that there are many intangible factors affecting each rate differently, e.g. the same rates may assume different importance according to the type of present population and the type of incident, which vary according to the site. In addition, one area can be assessed differently according to the risk rates of the other surrounding zones. This is also very important when assessing risk reduction measurements. For example, the reduction of a risk rate from E-03 to E-04 in one zone (i.e. from 10^{-3} to 10^{-4} - one hundred deceased occurs in a lapse of ten thousand years, instead of one thousand years) affects the risk rate of the whole area, but the same improvement for a different point might result in a different contribution to the total rate. This variation in contribution is not quantifiable via F-N, or via contour. Therefore, there is the genuine opportunity to apply the AHP model to the problem in order to quantify intangibility and geographic distributions of risk throughout experts’ opinion on the present

situation or any other new proposal and to use this information as indirect quantitative measures, which can be aggregated for obtaining the global risk rate.

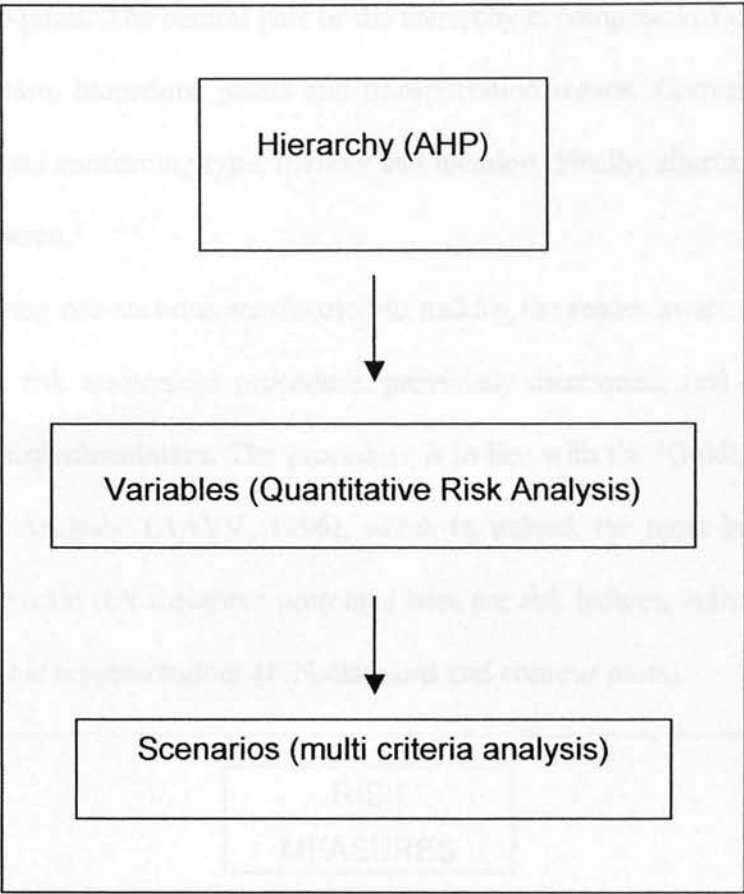


Figure 4: overall diagram of the experimental procedure

The AHP model has been selected because of its main features, in particular: its capability to deal with both qualitative and quantitative data, and the use of a hierarchy, which is particularly suitable for the complexity of the problem (actually the hierarchical order is a point of similarity between the AHP and the usual procedure). The hierarchy allows weighting the relationship among the elements of the problem (so that every risk measure can be considered in relation to them) and aggregating the local risk rates in a single value.

The main goal is ‘risk reduction of the impact area’; the sub goals are: ‘reduction of fire risk, explosion risk and toxic substance emission risk’. Since the area has been divided into zones having almost the same F-N value, each of them is compared to the others in relation to the sub goals. The central part of the hierarchy is composed of criteria affecting F-N values: population, hazardous plants and transportation means. Conventionally, they are split into simple data concerning type, number and location. Finally, alternatives are placed at the base of the scheme.

The following sub-sections are devoted to making the reader aware of the Italian EPA usual quantitative risk assessment procedure, previously mentioned, and carried out in the first stage of this experimentation. The procedure is in line with the ‘Guidelines for Chemical Quantitative Risk Analysis’ (AAVV, 1996), which is, indeed, the most important reference for this topic. The main risk measures presented here are risk indices, individual risk, societal risk and their graphic representations (F-N diagrams and contour plots).

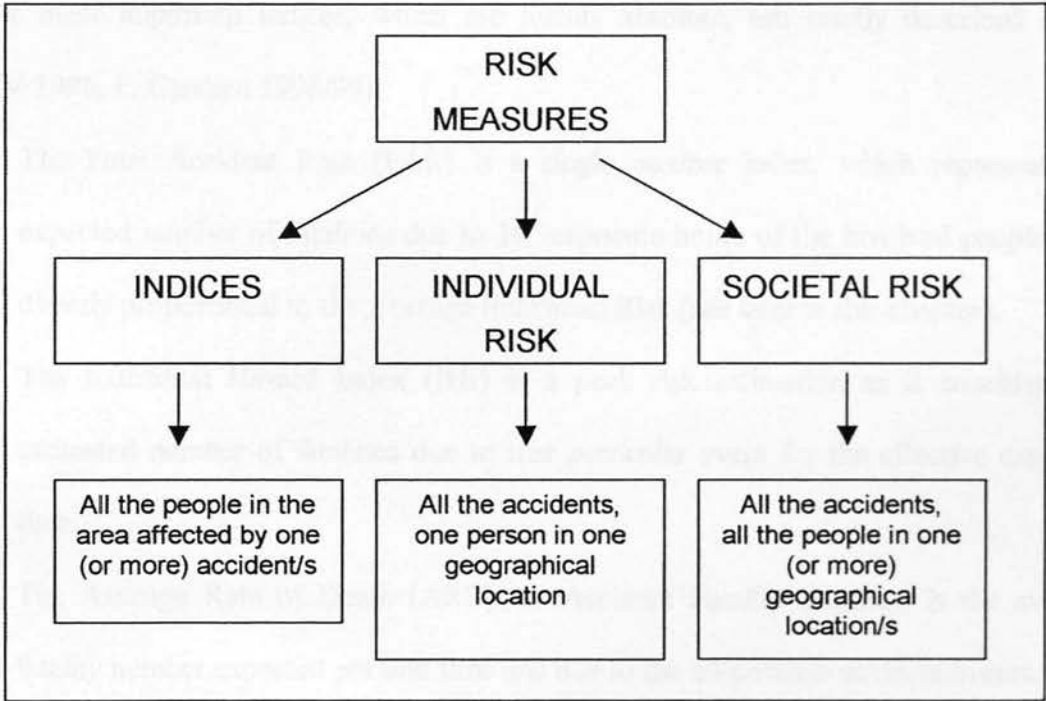


Figure 5: the most common risk measures and their main features

2.2. Risk measures

2.2.1. The risk indices

These indices may be single numbers as well as tabulations, representing a measure of consequences (usually fatality) per unit of time. They are very simple tools for estimating the risk in both a relative and an absolute way. Thus, they were very common until a few years ago; at the moment they are still in use when fast and condensed risk estimation is needed. In Italy, for example, each conductor of any plant at major hazard is required to provide risk indices should more detailed data not be available (which in reality is the norm).

Relative estimation is typical of indices based on accident consequences; conversely, absolute ones are based on their comparisons with a generally accepted quantitative target. However, limitation on their use relates to the fact that an absolute scale for accepting or rejecting a risk rate does not exist, given that each consequence (or quantitative target) can be judged differently by different people (AAVV 1996).

The most important indices, which are mainly absolute, are briefly described below (AAVV 1996, F. Candian 1998/99):

- The Fatal Accident Rate (FAR) is a single number index, which represents the expected number of fatalities due to 10^8 exposure hours of the involved people. It is directly proportional to the Average Individual Risk (see later in this chapter).
- The Individual Hazard Index (IHI) is a peak risk estimation as it considers the estimated number of fatalities due to that particular event for the effective exposure time.
- The Average Rate of Death (ARD), or Accident Fatality Number, is the average fatality number expected per unit time and due to the all-possible accident events.

- The Equivalent Social Cost Index (ESCI) is very similar to the previous one, with the exception that it includes also a factor estimating the society's aversion to large consequence accidents.
- The Mortality Index (MI), or Mortality Number, is a hazard index rather than a risk based one¹. In fact, it considers the average ratio of casualties to the mass of substance (or energy) released, derived from the observation of the historical record. Due to its nature, it is seldom applied to estimate the potential hazard of toxic material storage.
- The Economic Index (EI) is very similar to FAR, which is widely used by many private companies for financial estimation of loss, hence, outside the scope of this research.

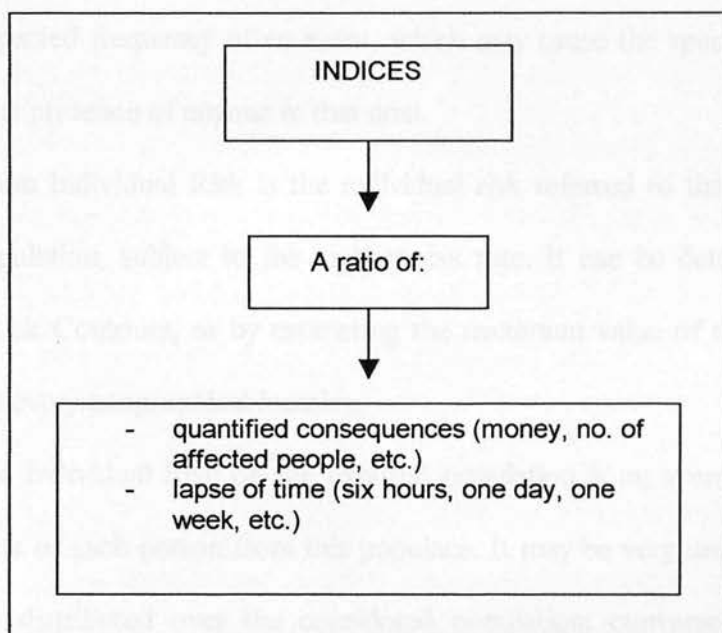


Figure 6: risk indices

¹ Hazard is referred to a chemical or physical condition, which may cause damage; while risk is defined as a measure of economic loss or human injury. See the glossary.

2.2.2. The individual risk

The individual risk is a more complete and evolved methodology for estimating the risk to an individual in the vicinity of a hazard (in a sort of way, a risk index in a precise location). However it is seldom limited to risk estimation of irreversible injury (or fatality) as historical data on different degrees of injuries is not usually sufficient. Its measurement includes many different factors: the nature of the injury, the likelihood of the injury occurring, the considered time period. Furthermore, it can be expressed differently according to the scope of the risk estimation, i.e. to estimate the hazard of the most exposed individual, an average individual, a group in a particular place, etc. The followings are the most important definitions of some individual risk measures (AAVV 1996, F. Candian 1998/99):

- The Individual Risk Contours are geographic representations of the individual risk in terms of expected frequency of an event, which may cause the specific level of harm regardless the presence of anyone in that area.
- The Maximum Individual Risk is the individual risk referred to the person, from an exposed population, subject to the highest risk rate. It can be determined from the Individual Risk Contours, or by estimating the maximum value of the individual risk computed at every geographical location.
- The Average Individual Risk on the exposed population is an averaged value of the individual risk of each person from this populace. It may be very useful when the risk is uniformly distributed over the considered population; conversely, it might lead therefore to misleading results in the case of a non-homogeneous distribution of risk.
- The Average Individual Risk on total population is a simplified measure of the individual risk since it does not consider whether all the people in the population are exposed to the potential event. It might create misleading results. Indeed, the larger the selected population, the lower the estimated risk.

- Average Individual Risk calculated on the base of the actual exposing time due to working activity, its location in the area and the type of activity.

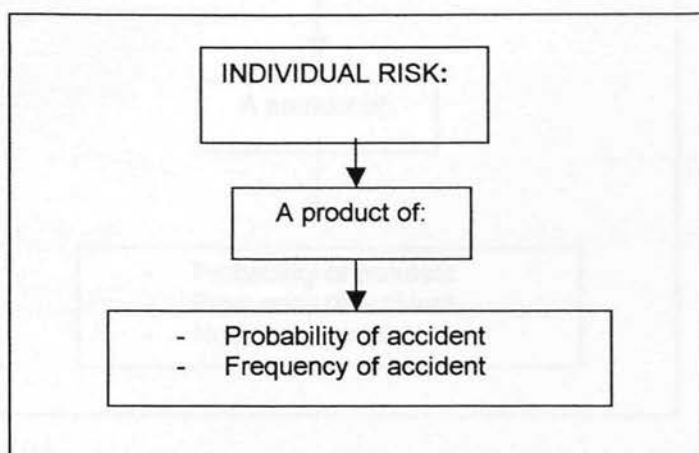


Figure 7: Individual Risk.

2.2.3. The Societal Risk

The societal risk is a measure of the potential effect of major accidents to a group of people; in a roundabout way, it is a global risk measure. It is usually measured in terms of frequency distribution of multiple events and can be derived from the Individual one (AAVV 1996, F. Candian 1998/99). Indeed, its measurement requires the same frequency and consequence data, so that sometime it can also be expressed in the same ways as the latter. The difference between the two is that the societal one requires complete information of the considered group of persons, i.e. type of population (residential, industrial, etc.), the likelihood of persons being present, and possible mitigation factors. Therefore, they are not the same thing and to derive one from the other would also imply additional calculation. Both societal and individual risks can be adopted to estimate the efficacy of any risk reduction measurement, or to assess the toleration of a risk scenario.

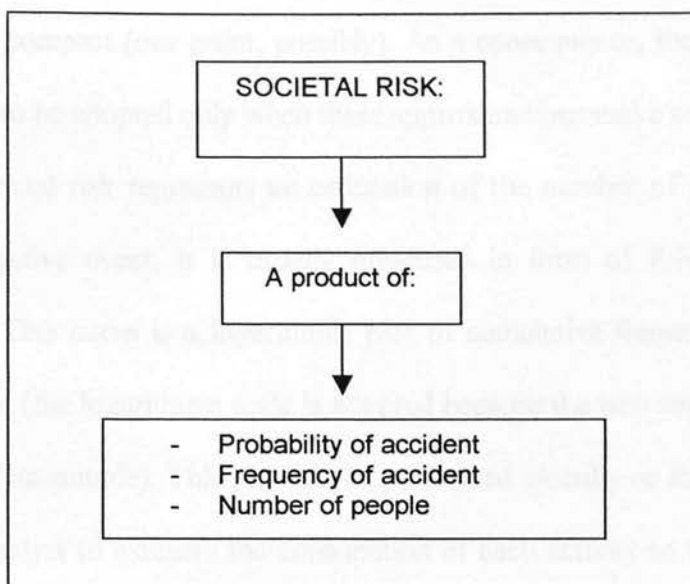


Figure 8: Societal Risk

2.3. Risk representation

Risk can be measured on the basis both of injury and fatality. The first can be less disturbing than the latter; therefore, the people's adversity to risk may result as different. However, it is very difficult to measure and compare different degrees and types of injury in the same analysis. For this reason, it is usually preferred to estimate the potential fatalities as a measure of standard injury.

The risk representation can be of different forms, according to the scope of the assessment (i.e. relative or absolute); therefore the final data is usually presented in terms of single number index, table, graph, and map. Risk Indices are always presented in form of tables referring to different types of industrial activities (AAVV 1996, F. Candian 1998/99, ANPA 1998). The individual risk is usually represented in form of contour. Risk contours are 'iso-risk' lines connecting geographical points of equal individual risk. Therefore, they can easily represent the distribution of risk on a map. Risk profiles are similar to the contours, with the exception that they consider the distribution of risk to be equal in all directions and

the source to be compact (one point, possibly). As a consequence, they are simpler than the contours but are to be adopted only when these approximations make sense.

Since societal risk represents an estimation of the number of people, which may be subject to a negative event, it is usually presented in form of F-N curve (Frequency – Number curve). This curve is a logarithmic plot of cumulative frequency versus number of potential fatalities (the logarithmic scale is adopted because the two variables may range over several orders of magnitude). This plot can be performed globally or for different activities; it may allow the analyst to estimate the contribution of each activity to the global risk and the comparison between this data and F-N plots due to natural hazards, for example. The societal risk can be represented by tables as well. This way of presenting the information is quite raw but very simple and suitable for non-specialists as the fatalities are grouped into few classes of size (e.g. $a=(1-10)$, $b=(11-100)$, etc.).

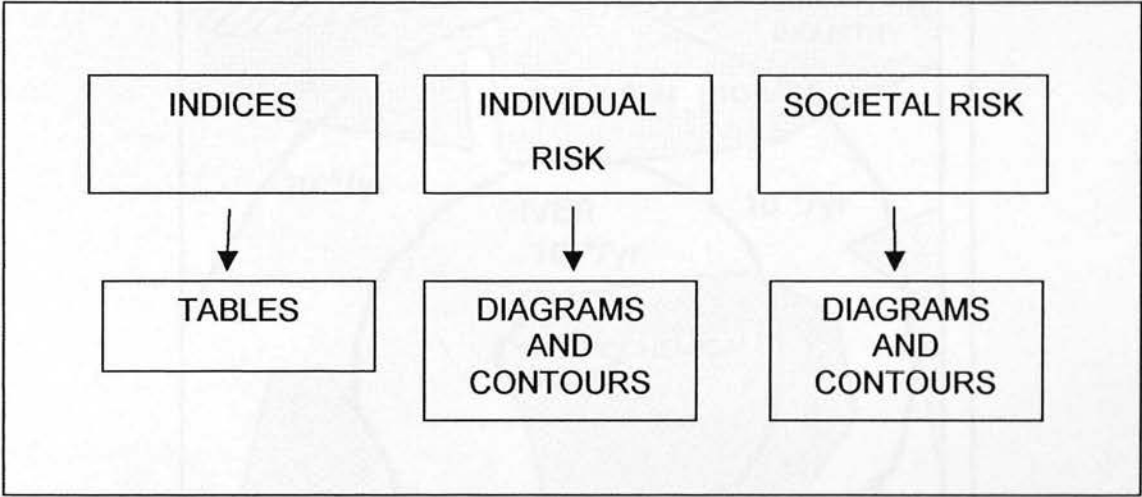


Figure9: risk measures and outputs

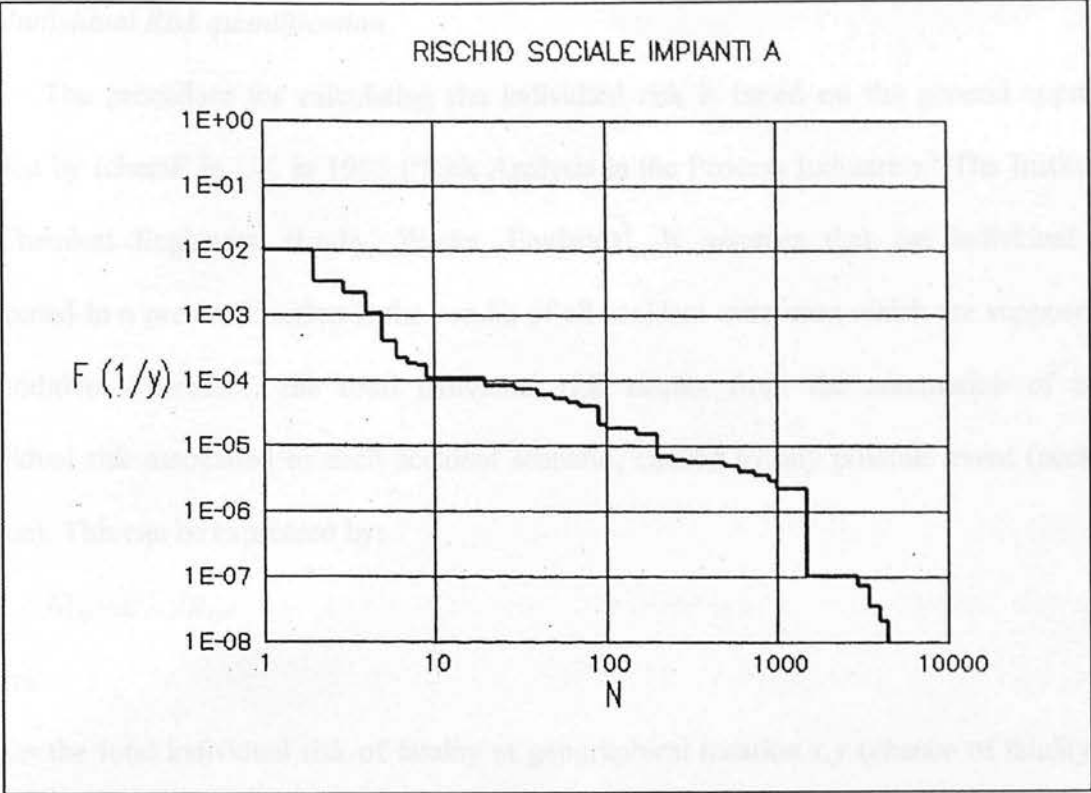


Figure 10: one example of F-N diagram of societal risk (ANPA 1999).

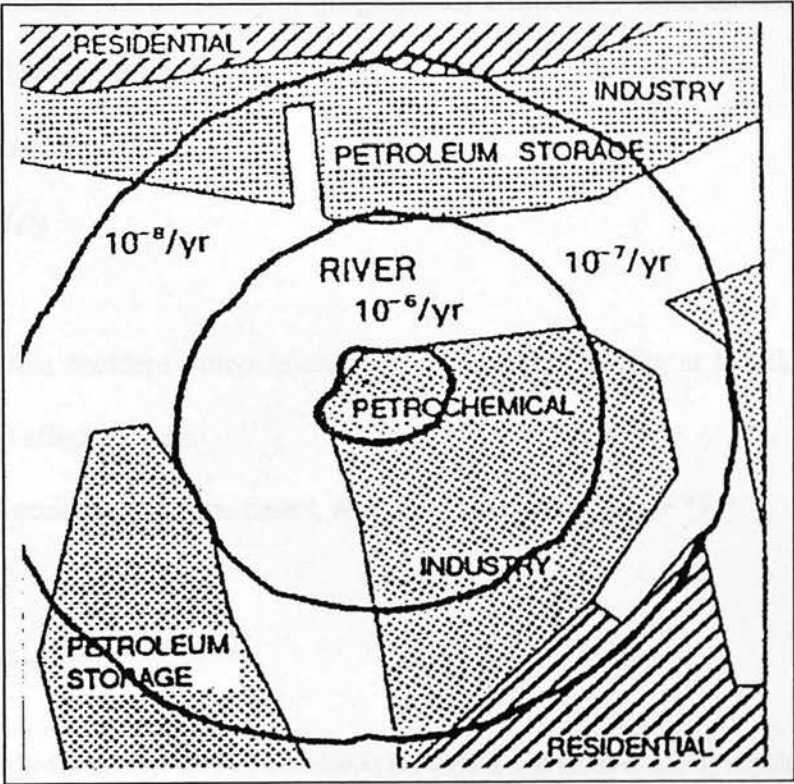


Figure 11: an example of individual risk contours (ANPA 1999).

2.4. Individual Risk quantification

The procedure for calculating the individual risk is based on the general approach studied by IchemE in UK in 1985 ('Risk Analysis in the Process Industries.' The Institution of Chemical Engineers, Rugby, Warks, England)². It assumes that the individual risk computed in a precise location is the results of all accident outcomes which are supposed to be additive. Therefore, the total individual risk results from the summation of every individual risk associated to each accident scenario, caused by any possible event (accident source). This can be expressed by:

$$IR_{xy} = \sum_{i=1}^n IR_{xyi}$$

Where:

IR_{xy} = the total individual risk of fatality at geographical location x,y (chance of fatality per year or yr^{-1}).

IR_{xyi} = the individual risk of fatality at geographical location x,y from accident outcome case i (chance of fatality per year or yr^{-1}).

Inputs to the equations are:

$$IR_{xyi} = f_i p_{fi}$$

Where:

p_{fi} = probability that accident outcome case i will result in a fatality at location x,y , from the consequence and effect models.

f_i = frequency of accident outcome case i , from frequency analysis (yr^{-1}).

In particular:

$$f_i = F_i p_{oi} p_{oci}$$

² The standard procedure for risk calculation is complex and involves highly sophisticated calculation models and algorithms. In this section only a general overview will be presented. More detailed information can be found in the scientific literature in the bibliography (AAVV 1996, F. Candian 1998/99, ANPA 1998, regione Emilia Romagna 1996).

Where:

F_I is the frequency of accident I, which has accident outcome case i as one of its accident outcome cases (yr^{-1}).

p_{oi} = probability that the accident outcome, having i as one of its accident outcome cases, occurs, given that accident I has occurred.

p_{oci} = probability that the accident outcome case i occurs given the occurrence of the precursor accident I and the accident outcome corresponding to the outcome case i.

It has to be noted that the calculation of f_i requires the assessment of each accident outcome, which is associated to a probability. These outcomes are usually further broken down into accident outcome cases and the relative probabilities of occurrence, which may be so numerous that an event tree (or a failure tree) is commonly used to evaluate these relationships.

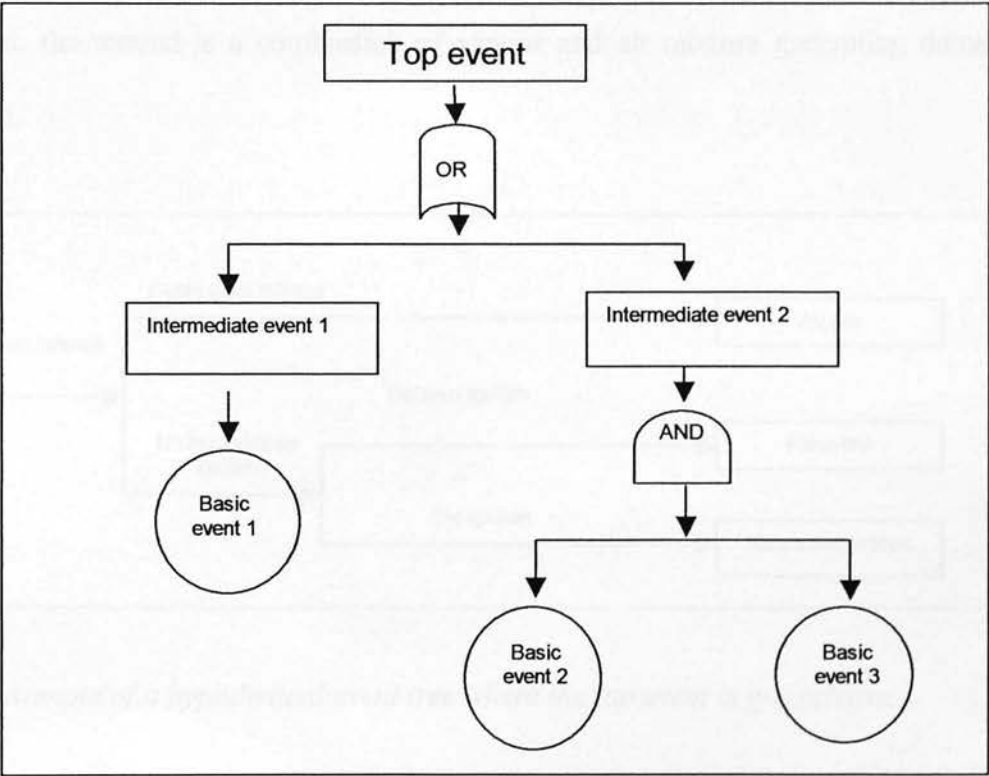


Figure 12: example of a hypothetical failure tree.

The event tree and fault tree analyses are logical and graphical techniques based on Boolean relationship between adjacent elements. They are used to identify and quantify possible outcomes following an initial event and to estimate the frequency of a hazardous accident, respectively. An example can be the analysis of a failure of valves for temperature control, which sometimes may generate a fire. Therefore, in the failure tree (see figure12), the gas release may be generated by the failure of emergency devices 1 and 2 (intermediate events), which command the valves to open in the case of a failure of one of the three valves (basic events). In the event tree (figure 13) the failure of one valve is on the top and the two alternatives below: fire and no-fire. Below them, there can be other related parts and failure, which lead to one or more final events (outcome) depending to what branch of the graph is considered: jet fire, flash fire or no consequences. Jet fire and Flash fire are typical uncontrolled gas combustions: the first results from pressurised release of inflammable gas and/or liquid, the second is a combustion of vapour and air mixture generating damaging overpressure.

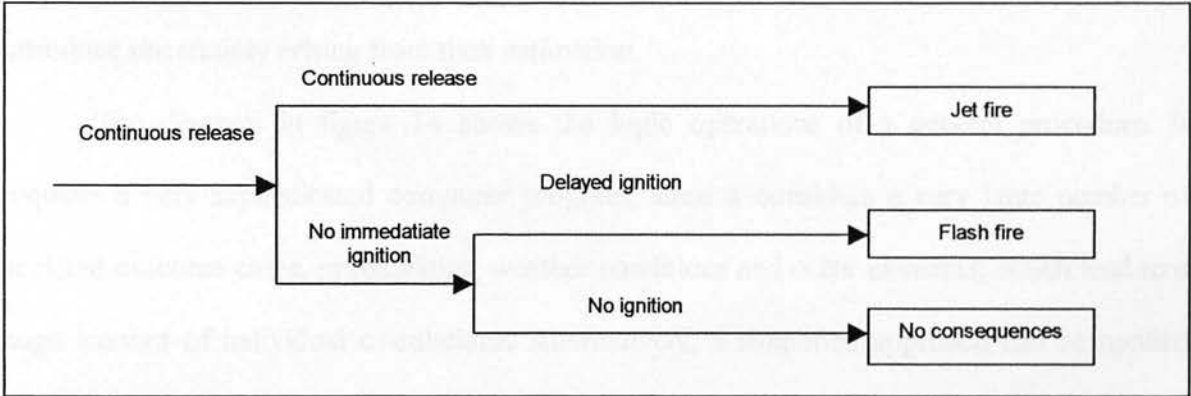


Figure 13: example of a hypothetical event tree where the top event is gas release.

A general standard procedure for individual risk quantification includes the above-mentioned calculations. In particular, IR_{xy} , IR_{xyi} and f_i must be calculated in every point around each potential accident source (plant or facility). As an example, the reader may consider a release of non-toxic flammable substances (accident), which can result in many different events such as fires and explosions (accident outcomes), in diverse places and conditions. Therefore, frequency and effect zones have to be defined for each case (the appropriate methodology may be found in AAVV 1996 and ANPA 1998). Complete information on the ignition sources and weather condition is also a prerogative. The general result is a list of individual risk values, related to each location xy within the study case area. This set of values may be presented in a table or plotted on a map where risk contours may be drawn by connecting points of equal risk rate manually or by any standard graphic program, which can interpolate the points. Mitigation factors too, like shelter or escape evacuation, should be taken into account, as the individual risk may be greatly affected (the contours can differ by a factor of 10 or more depending on whether or not the mitigation factors are considered). However, mitigation factors can increase the difficulty of the risk calculation and may introduce uncertainty arising from their estimation.

The diagram in figure 14 shows the logic operations of a general procedure. It requires a very sophisticated computer program, since it considers a very large number of accident outcome cases, probabilities, weather conditions and other elements, which lead to a huge amount of individual calculations. Alternatively, a simplified approach can be applied which does not require complete information of the individual risk in each point of the area, rather the risk at a few relevant locations. In such a way, the former procedure is only applied to points where individual risk constitutes critical information for the analyst and the decision maker, while geographical risk distribution does not.

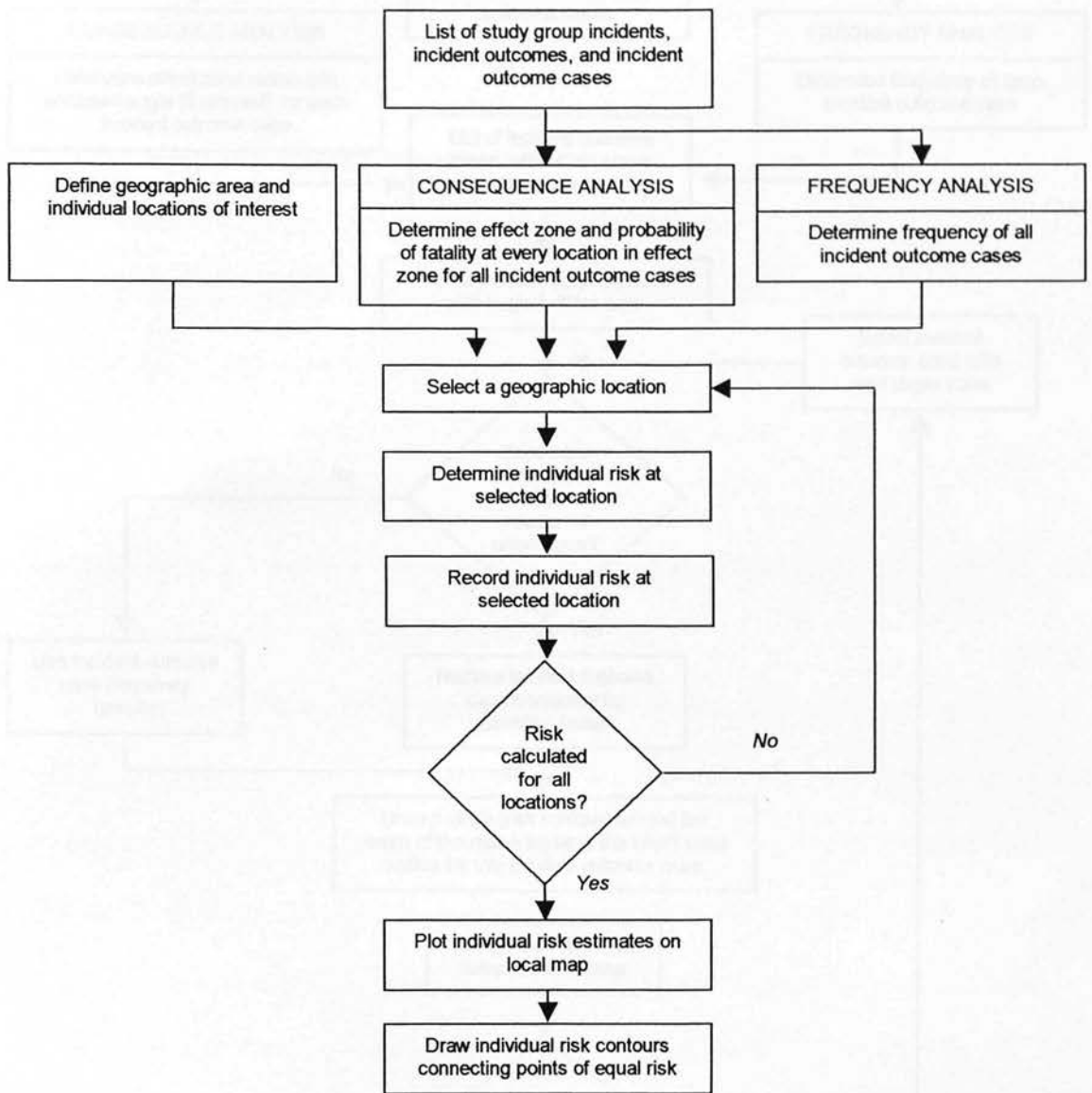


Figure 14: general procedure for calculating individual risk contours (from AAVV, Chemical Process Quantitative Risk Analysis, Center for Chemical Process Safety of the American Institute of Chemical Engineers, USA).

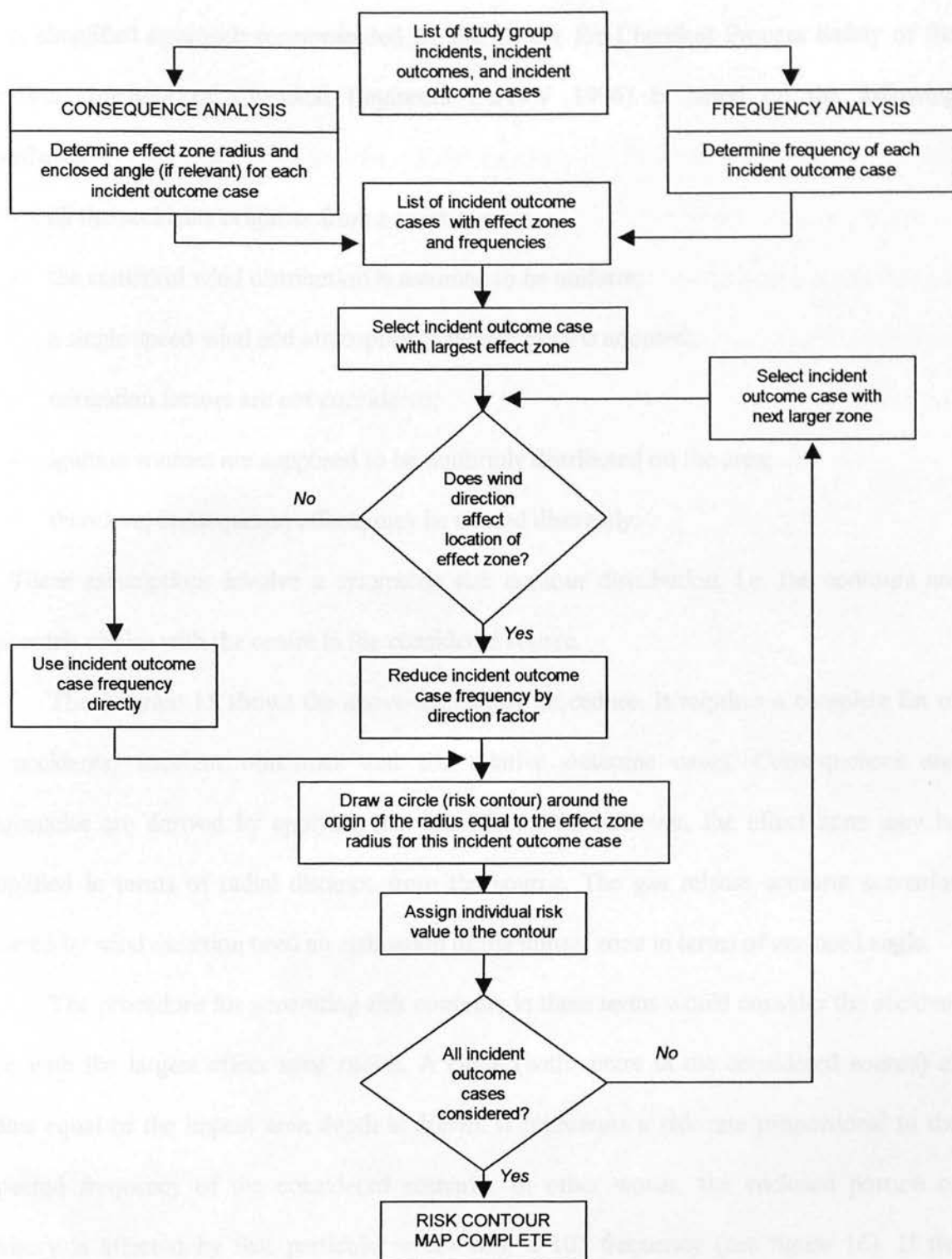


Figure 15: Simplified procedure for calculating individual risk contours (from AAVV, Chemical Process Quantitative Risk Analysis, Center for Chemical Process Safety of the American Institute of Chemical Engineers, USA).

A simplified approach recommended by the Center for Chemical Process Safety of the American Institute of Chemical Engineers (AIChE 1996) is based on the following hypotheses:

- all the accidents originate from a point source;
- the statistical wind distribution is assumed to be uniform;
- a single speed wind and atmospheric stability class is adopted;
- mitigation factors are not considered;
- ignition sources are supposed to be uniformly distributed on the area;
- therefore, consequence effects may be treated discretely.

These assumptions involve a symmetric risk contour distribution, i.e. the contours are concentric circles with the centre in the considered source.

The diagram 15 shows the above-mentioned procedure. It requires a complete list of all accidents, accident outcomes and the relative outcome cases. Consequences and frequencies are derived by applying the usual formulas; however, the effect zone may be simplified in terms of radial distance from the source. The gas release accident scenarios affected by wind direction need an estimation of the impact zone in terms of enclosed angle.

The procedure for generating risk contours in these terms would consider the accident case with the largest effect zone radius. A circle (with centre in the considered source) of radius equal to the impact area depth is drawn. It represents a risk rate proportional to the expected frequency of the considered scenario. In other words, the enclosed portion of territory is affected by that particular event with a 10^{-n} frequency (see figure 16). If the outcome case (gas release) is affected by wind direction, the frequency value should be reduced proportionally to the probability that the wind will be blowing in a particular direction for a fraction of time. Practically it is equivalent to the general approach, with the

exception that the scenario is split into many sub scenarios each of which corresponds to a single wind direction and is associated to the expected frequency multiplied by the probability associated to that particular direction. Once the individual risk has been associated to a contour, the next step of the procedure is to consider a smaller scenario contour and repeat the procedure, taking into account the fact that these locations are subject to the considered scenario as well as all the previous ones which have a longer impact radius. As a consequence, its risk value is the result of a summation of all the possible scenarios, which the location is at risk. The final map results in the form of a series of concentric circles, each of which associated to an individual risk rate.

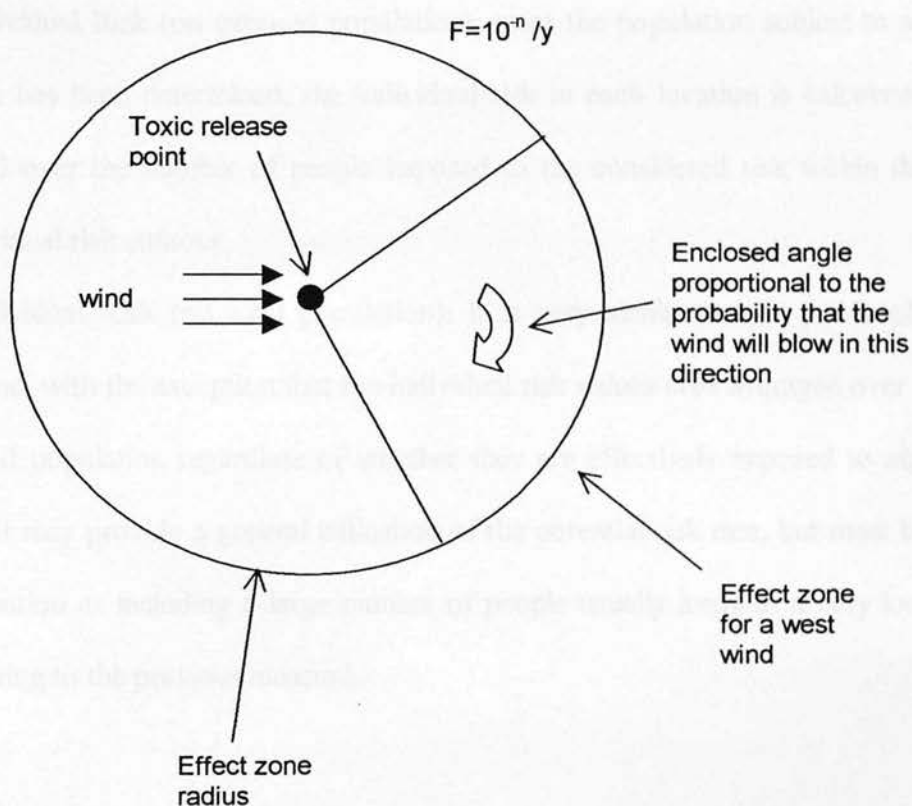


Figure 16: Effect zone for an accident outcome case depending on wind direction, simplified individual risk approach from AAVV, Chemical Process Quantitative Risk Analysis, Center for Chemical Process Safety of the American Institute of Chemical Engineers, USA).

2.5. Other individual risk measures

The previous section illustrates the general procedures for calculating the individual risk in any location close to a plant, and plotting the appropriate risk contour. However, it requires complete knowledge on the local population in terms of potential accident causes, as people may affect the realisation of a hazard and the determine risk level. Some indices and measures already mentioned at pages 20 and 21 consider the population in terms of exposed persons, too (AAVV 1996, F. Candian 1998/99).

- a) **Maximum Individual Risk:** it is determined by calculating the individual risk in every location of the area where people are, and searching for the maximum risk value.
- b) **Average Individual Risk (on exposed population):** once the population subject to an effective risk has been determined, the individual risk in each location is calculated and averaged over the number of people exposed to the considered risk within the farthest individual risk contour.
- c) **Average Individual Risk (on total population):** it is very similar to the previously mentioned one, with the exception that the individual risk values area averaged over a predetermined population regardless of whether they are effectively exposed to any risk or not. It may provide a general indication of the potential risk rate, but must be used with caution as including a large number of people usually leads to a very low value comparing to the previous measure.

2.6. Societal Risk quantification

As previously mentioned, the following procedure for calculating the societal F-N risk curves is based on the methodology developed by IchemE (U.K.) in 1985. It requires the same information as for the Individual Risk calculation, along with detailed knowledge on local population. In particular:

- Information on population composition (residents, tourists, etc.);
- Individuation of particularly vulnerable persons or groups of people (students, the elderly, etc.);
- Information on time-of day, day-of-week, months-of-year presence of people;
- Information on percentage of time people are indoor rather than outdoors, in order to consider mitigation factors.

For simplicity, differences in population composition and distribution may be treated as homogeneous population. However, it can lead to misleading results, in particular when a concentration of persons is occasional. Therefore, it is preferable to associate to each group of people a frequency of occurrence, which will be multiplied for the appropriate total accident frequency.

The general procedure adopted by the Italian EPA (recommended by the Center for Chemical Process Safety of the American Institute of Chemical Engineers) for calculating the Societal Risk is similar to the one of Individual Risk calculation. In particular, the first steps are the same; however it is necessary to combine this individual risk data with the above mentioned population information, in order to determine the effective number of people affected by each accident outcome case. The number of fatalities is calculated by taking all the accident scenarios into account, each of which is associated to an expected frequency of occurrence, and the relative number of affected people. The results are related numbers F-N representing a cumulative frequency F of an event versus consequences (expresses as number of fatalities N), in logarithmic scale:

$$N_i = \sum_{xy} (P_{xy} \times p_{fi}) \text{ and } F_N = \sum_i F_i \text{ for all accident outcome case } i \text{ for which } N_i \geq N$$

where N_i = number of fatalities resulting from accident outcome case i

P_{xy} = number of people at location x,y

p_{fi} is as defined in individual risk

F_N = frequency of all accident outcome cases affecting N or more people

F_i = frequency of accidents outcome case i

The F - N values may be presented as a curve or contours as well.

The societal risk calculation is extremely time consuming due to the fact that the following information for each accident outcome and accident outcome case has to be known:

- a. Every accident outcome case and its consequences,
- b. Weather condition,
- c. Wind direction,
- d. Ignition case,
- e. Population case.

Practically, each accident must be evaluated for n different cases where

$$n = W \times N \times I \times P;$$

given W the classes of atmospheric condition usually varying from two to six,

N the number of wind directions varying from eight to sixteen,

I the number of ignition cases (usually more than one),

P the number of population cases (which are at least two).

In general, 'case' is a technical word that refers to the quantitative definition of a single result of the potential consequences of the accident. Therefore, 'Population case' means the number of people affected by the accident while ignition cases refer to the parameters, which measure the probability of ignition.

Fortunately, mitigation factors, when present, can speed up the calculation as they can reduce quite a lot the probability of fatality.

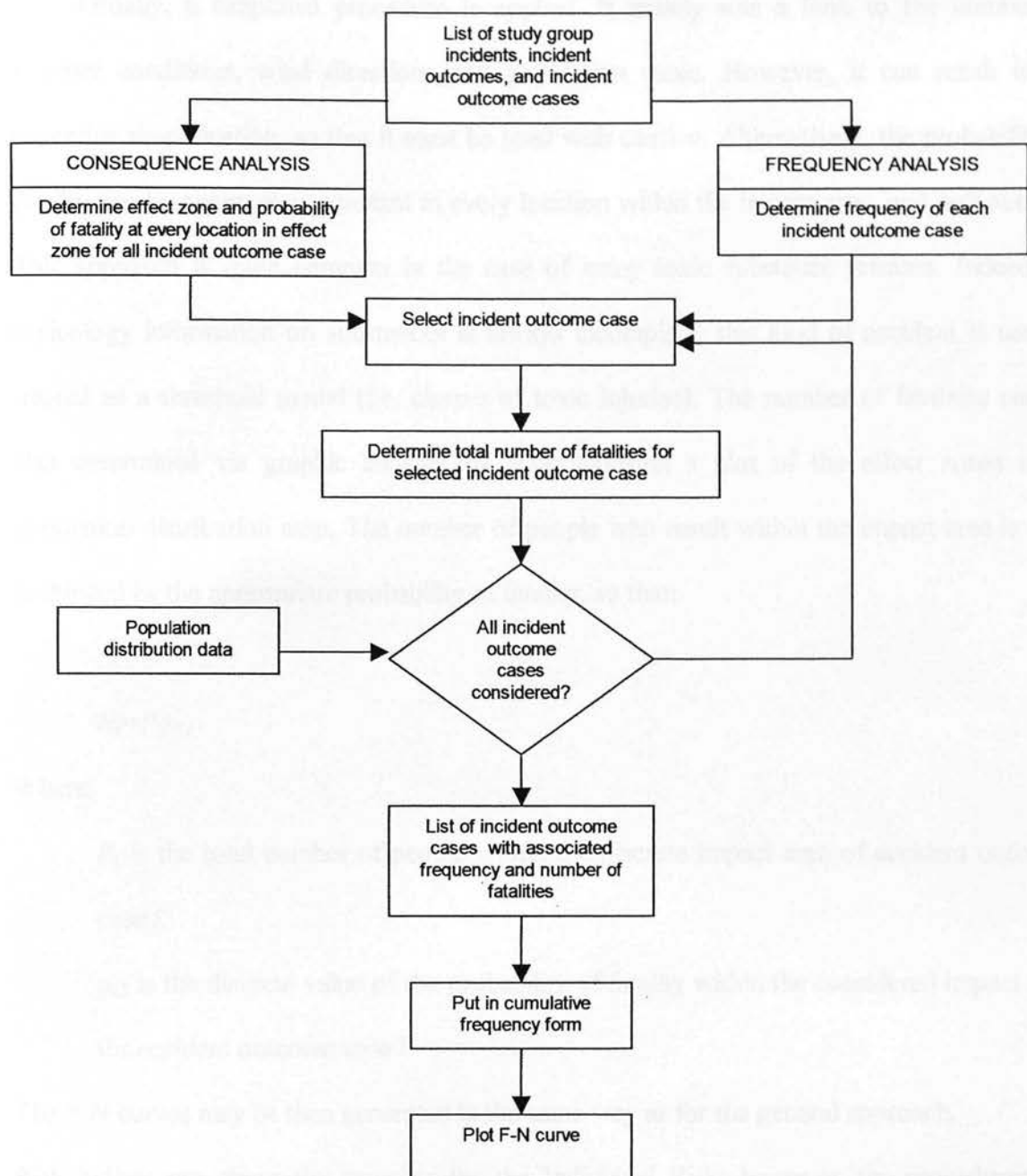


Figure 17: general procedure for calculating societal risk F-N curves (from AAVV, Chemical Process Quantitative Risk Analysis, Center for Chemical Process Safety of the American Institute of Chemical Engineers, USA).

Usually, a simplified procedure is applied. It mainly sets a limit to the number of weather conditions, wind directions and population cases. However, it can result in an excessive simplification, so that it must be used with caution. Alternatively, the probability of fatality can be assumed as constant in every location within the impact area, and null outside. This approach is quite common in the case of many toxic substance releases. Indeed, as toxicology information on substances is always incomplete, this kind of accident is usually treated as a threshold model (i.e. classes of toxic injuries). The number of fatalities can be also determined via graphic analysis by superimposing a plot of the effect zones on a population distribution map. The number of people who result within the impact area is then multiplied by the appropriate probability of fatality, so that:

$$N_i = P_i p_{f,i}$$

Where:

P_i is the total number of people within the discrete impact area of accident outcome case i .

$p_{f,i}$ is the discrete value of the probability of fatality within the considered impact area for accident outcome case i .

The F-N curves may be then generated in the same way as for the general approach.

Risk indices are about the same as for the Individual Risk; however, the procedures for calculating them are slightly different, while the input data is still the same.

The most common ones are³:

- The Average Rate of Death,

³ Their definition can be found at page 21, while complete information on them is in the scientific literature listed at the end of this report.

- The Equivalent Social Cost,
- The Fatal Accident Rate,
- The individual Hazard Index,
- The Mortality Index.

3.1. Environmental evaluation methods

As previously mentioned, the Analytic Hierarchy Process - adopted in this work - is a multi criteria tool. This section introduces the concept of multi criteria analysis in environmental issues by reviewing the historical evolution of this class of models.

During the last decades, many techniques for analysing, measuring and predicting impacts on the environment have been studied by different disciplines, such as economics, ecology, and engineering. However, the most important studies have been made in the field of economics, where the prediction of market behaviour in general is the most important issue (E. D. Bell, H. Raiffa e A. Tiesky 1994, H. Voogd 1983) - see section two, for more information on this issue.

Cost-Benefit Analysis (CBA) was recognized to be the starting point for many different applications in the sixties and seventies in USA and UK (F. Steiner 1994, H. Voogd 1983, F. Nuti 1987, L. F. Fusco and P. Nijkamp 1997, K. J. Button and P. J. Baker 1975). It is based on the simple concept that a project is accepted if the benefits are more than the costs: $b > c$, where b and c are monetary measures of costs and benefits. It is composed of three main phases: determination of cost and benefits; evaluation of costs and benefits; comparisons between costs and benefits. Evidently, the assessment of any scenario is performed within the context of monetary aspects, and the inclusion of social and environmental aspects has made this approach very difficult. As a consequence, different standard indirect measures of values have been introduced in order to compute these aspects: the *Contingent Valuation Methods*. They form a joint between Cost-Benefit Analysis and the traditional survey research. Furthermore, they use the same factors of the C/B Analysis (though for a wider class of research on choice and pricing problems (A. Randall 1994, P. Copping and B. Slee 1994, K. Willis 1994). Examples are the WILLINGNESS TO PAY (W.T.P.), for obtaining a preferred situation, and the

WILLINGNESS TO ACCEPT (W.T.A.) *a compensation for tolerating a less-preferred situation*. Both of them elicit monetary values for public goods “not on the basis of the effective observed behaviour of subjects on the market, but with reference to an artificially structured market (hypothetical market). By means of surveys of potential purchasers, the necessary information is obtained in order to estimate the price consumers would be prepared to pay if the product were launched on the market.” (Sirchia, G. 1997 ‘The economic valuation of cultural heritage’, in Brandon P., Lombardi P., Bentivegna V., (ed.), *Evaluation of the Built Environment for Sustainability*, Chapman & Hall, London, pp.426-434). The first is based on the idea that one person would pay a specific sum of money for obtaining a benefit, which is the studied factor or a proxy criteria. This second value is based on the compensation principle: the irreplaceable loss or damage of a social or environmental sector, should be reimbursed. Even if each compensation can be computed in its proper unit, the method still uses market prices for the determination of these values. Different *indirect approaches* for dealing with non-monetary aspects were developed later by environmental economists (H. Voogd 1983). They are based on the measurement of indirect quantitative aspects, like the *Hedonic Pricing Model* (HPM) and the analyses of the people's behaviour (G. D. Garod 1994, J. Bateman 1994). The first one is a statistical analysis based on the observation that an item takes its value from its attributes, like location and environment. Consequently, the variation of one of these attributes induces a variation of the monetary value of the item. By using a mathematical model – an aggregating function based on coefficients, which weigh the importance of each attribute - the method is able to project the variation of price related to the change of these attributes (G. D. Garod 1994, J. Bateman 1994). The analysis of people behaviour measures in a monetary way one aspect of the human behaviour with respect to a particular environment (H. Voogd 1984). The participant reveals his choice directly by a questionnaire or implicitly by using the W.T.P in two different ways: the *Contingent Purchase Decision* and the *Contingent Policy Referendum*. In the former, more traditional

one, the respondent reveals his choice via decision to buy or not at a determined price; the object of the purchasing determines how implicit the response is. For example, a person can decide to buy or not a house within a determined area with particular environmental values. This could correspond to an implicit judgement on the environmental scenario. The second one is more direct, because the person is requested to vote yes or no to a hypothetical issue; but it involves mainly social-economical problems. Generally, the goal of a Contingent Valuation Method is to find a payment level (a threshold) over which a person is indifferent to pay for a derived good, advantage or service (K. Willis 1994, J. Bateman 1994). Next to the Cost/Benefit approach, some other pricing methods have been developed, such as *Cost/Effectiveness Analysis* (CEA), or *Balance Sheet* method (developed by Liechfield in the '70s-'80s), where the direct monetary standardization of all the aspects is avoided (S. Steiner 1994, K. J. Button and P. J. Barker 1975). In the CEA, the 'cost' of any scenario is directly related to the attainment of the objectives: the higher the costs, the less feasible the project. Thus, the costs are analysed and minimized, while the benefits are not considered because of their character of intangibility. The *Balance Sheet* method is a descriptive approach widely used in regional planning. It describes the effects of a plan for the various social sectors: the pros and cons are simply listed, grouped in different categories, and then analysed in terms of difference between income and outgoings. Usually, every aspect is measured by a monetary unit. However, non-monetary effects may be measured by their own unit, on ordinal or cardinal scale as well. The link between these methods and the multi criteria analysis is the *Goal Achievement Matrix* of Morris Hill (F. Steiner 1994). The *Goal Achievement Matrix* is still based on costs and benefits; however, the context is no longer monetary. It is a proper method for comparing many different choice options regarding the different social groups involved. The main objectives of all the scenarios are listed and judged by every interested party. The judgement is composed of a number: the higher the number, the more the party's benefit. In addition each group can be associated to a number

corresponding to its 'social weight'. Consequently, by multiplying the 'weights' for the respective judge's scores, it is possible to obtain an overall score for every alternative. In this way, Hill introduced the *Weighted Summation Technique*. This is just a very simple and practical way of aggregating judgement weights with different priorities in one unique score. Basically it is based on the following simple mathematical definition:

$X = \sum w_i x_i$, where X is the total score, and x and w are the local score and weight respectively. Hill's matrix method has been recognized as the hard core of the *Multi Criteria Evaluation* (Voogd, H. 1983): this approach is the logical development of the monetary methodologies, jointly with the *Multi-Attribute Utility Theory*. The *Utility Theory* was developed in the Seventies by (H. Varian). It is based on the definition of the individual *utility function* of the decision maker; every alternative is then assessed by means of this function. The *utility function* is an analytical way – developed by Von Neuman - of quantifying how much an item performs the objective of the 'purchaser' (the planner or the politician, in this case): given a specific objective, it is possible to define a mathematical function that gives the variation of the decision maker's satisfaction related to the different alternatives. For example, a pool of people can be asked to assign a score reflecting their level of satisfaction (variable Y) for each level of air pollution (variable X), so that the relation $Y=f(X)$ represents an utility function (figure 18). However, the concept of utility function is widely explained in the section two, while most common standardization techniques are illustrated in chapter on the Analytic Hierarchy Process.

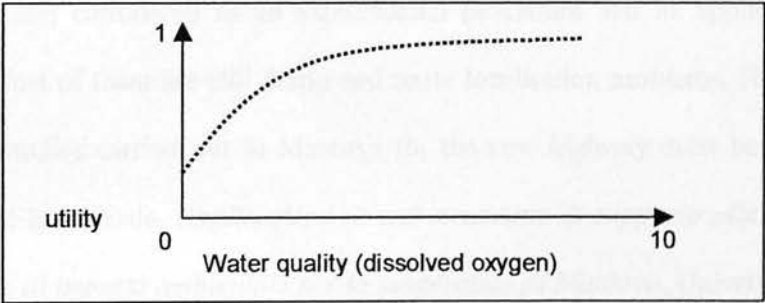


Figure 18: example of an utility function.

Finally, the *Multi Criteria Evaluation* approaches have been developed from Hill's first concept by many different authors¹ (H. Voogd 1983). It is widely used in different disciplines. Its core consists of one bi-dimensional matrix: the rows represent the alternatives, and the columns are the criteria by which the alternatives are judged. The elements of the matrix represent a standardized measurement of the 'utility' - the decision maker's satisfaction - of each alternative, relative to the criteria. The various methodologies differ from each other in the way they compute these values and aggregate them into some final scores. As we can see, this approach is a further development of the previous methodologies: the Cost/Benefit Analysis, the Goal Achievement matrix, and the Multi-Attribute Utility Theory. Multi-criteria evaluation has been seen as a very useful instrument to analyse the potentiality of an object/project/issue with respect to some particular aspects or priorities, in many different areas.

Nowadays, multi criteria analyses are common tools in many western countries, in particular in the Netherlands and in France (B.Roy 1990, H. Voogd 1983, R. Jansses, P. Nijkamp and P. Rietveld 1990, R. Jansses, P. Nijkamp and H. Voogd 1985), where, in fact, most of them have been developed. In general, they are widely applied in planning procedures and in any environmental impact assessment by the national authorities in the Netherlands (Jansses, P. Nijkamp and P. Rietveld 1990). Here, recently, they have also been applied to strategic environmental assessment, e.g. to assess wide urban plans and development programmes (L. Fusco and P. Nijkamp 1997). In Italy, multi criteria analysis is still considered as an experimental procedure and its applications as pilot projects. Most of them are still dump and route localisation problems. However, among them, the studies carried out in Mantova for the new highway must be mentioned (A. Colorni and E. Laniado, *Applicazione di uno strumento di supporto alle decisioni nella valutazione di impatto ambientale per la tangenziale di Mantova*, University of Milano –

¹ However, some authors recognise Filfredo Pareto - an Italian economist and sociologist of the XIX century, known for his application of mathematics to economic analysis - as the first who introduced the concept of multi criteria (L. Fusco e P. Nijkamp 1997).

internal paper) as well as a problem of dump localisation in Friuli Region (F. Marangon, *Corso di aggiornamento su procedure informatiche VIA*, IAL/University of Udine – internal paper). In addition, interesting Italian case studies are presented in L. Fusco and P. Nijcamp (1997) on a variety of issues: landscape, planning, urban restoration and historical monument estimation.

To date, the Italian EPA has not used these techniques, even if its interests in these has been recently demonstrated by the organisation of some internal conferences on multi criteria analysis (L. Brisighella, *L'analisi a multi criteria*, University of Padova/ARPAV). The present application on Porto Marghera testifies to this interest and is considered by the Italian EPA as an important pilot project (see the EPA's letter in annex 5) of multi criteria analysis applied to regional planning. This is intended to be further developed in the next few years.

3.2. The multi criteria analytic model AHP

In order to understand the real world, an analyst must assume that he can describe it somehow, identify and define relationships among its parts and apply its judgement capability to relate these parts in a priority order. However, human judgement capability is related to the ability of identifying different properties and measuring intensities. In science, the range of certain measurements can vary widely, whereas the range of human values and feeling is quite limited and covers few orders of magnitude. According to Saaty (Saaty 1995), the real world and its phenomenon - causal influences and their effects - can be analysed in two different ways. The first is the traditional deductive logic procedure, which is mainly linear; i.e. from initial assumptions to many separate conclusions by deducing them. Separate conclusions must be related each other in some coherent way. Sometimes, this requires high experience and imagination. The second approach is holistic in the sense that all factors and criteria are arranged in advance in a hierarchy, which denotes the logic relationships among them. This second approach

requires deep knowledge of the issue, rather than ability in reasoning logically at the end of the process.

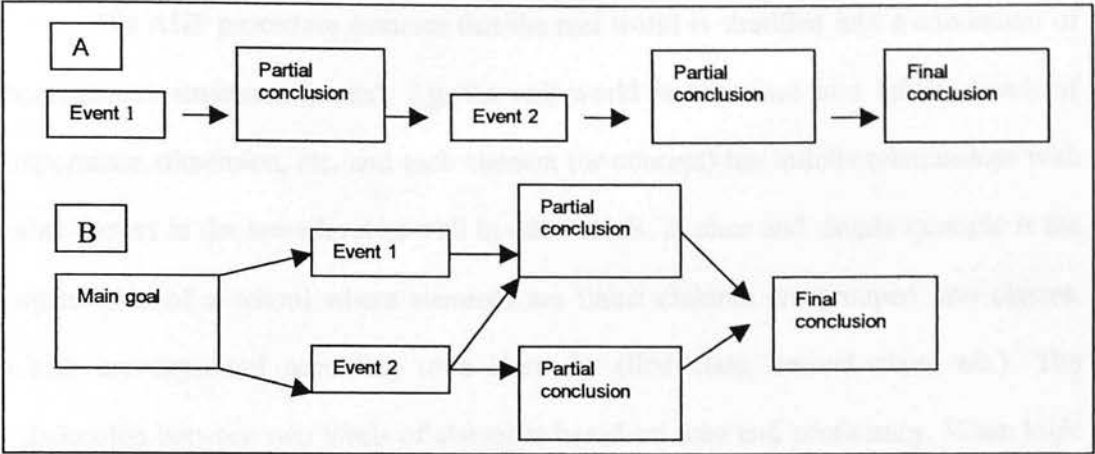


Figure 19: examples of linear (A) and holistic (B) approaches.

In line with these considerations, Thomas L. Saaty developed the Analytic Hierarchy Process (in 1977), a mixed – qualitative and quantitative – decision procedure based on a holistic approach. From this point of view, this method seems to be a very useful approach when dealing with complex problems. In particular, it is concerned with the relationship between alternative actions, choice, priorities, etc. that need to be evaluated on the basis of our system of values. The hierarchic structure can help in doing this. In particular, this approach can lead to:

- structuring a complex problem with (or without) internal/external dependence;
- eliciting judgements which are supposed to reflect perceptions;
- the representation of those judgements;
- summing up of results;
- sensitivity analysis of judgements and forecasting.

However, it must be noted that AHP is a “(...) non-linear framework for carrying out both deductive and inductive thinking without the use of syllogism by taking several factors into consideration simultaneously and allowing for dependence and for feedback,

and making numerical tradeoffs arrive at a synthesis or conclusion” (Saaty, 1996, page 21).

The AHP procedure assumes that the real world is stratified into a continuum of homogenous structures (strata), e.g. the real world is organised into infinite levels of importance, dimension, etc. and each element (or concept) has infinite relationships with other factors in the same level as well in other levels. A clear and simple example is the organisation of a school where elements are finite: children are grouped into classes, which are organised according to a hierarchy (first class, second class, etc.). The relationship between two levels of classes is based on time and proficiency. When logic seems to be insufficient, the human mind tends to relate to all these strata by appealing to perception and imagination. In particular, it is only with our imagination that we try to relate un-homogeneous strata and apply deductive logic (Saaty 1996).However, it is sometimes not possible as very small levels cannot be linked meaningfully to very large ones (an example can be quantum theory and astrophysics). In this case, a person needs a holistic approach. Hierarchy and ratio-scale thinking are the main tools for this kind of analysis. “This process is inherent in nature’s design of our neural brain” (Saaty 1996, page 19)

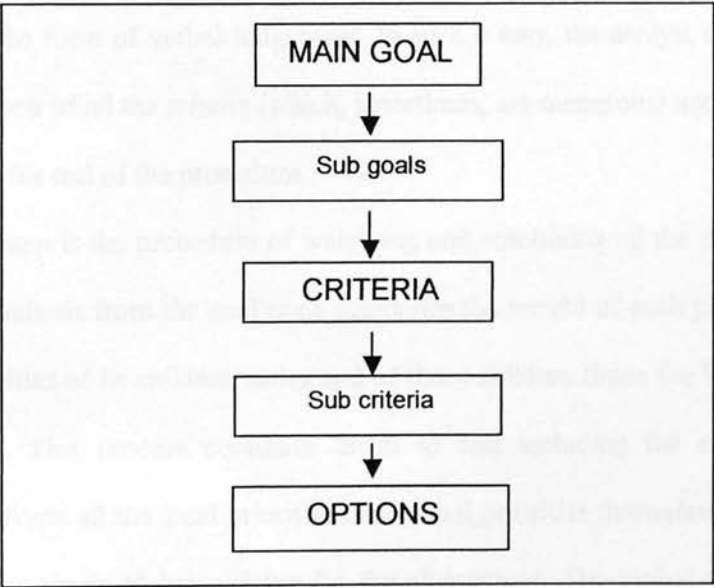


Figure 20: the general diagram of the Analytic Hierarchy Procedure

The AHP model can be summarised in three main phases. The first step of the procedure is the construction of a hierarchy of all the elements of the analysed problem. This is a way of ordering the elements in a structure, which represents the dominance levels of the problem (A. Giangrande 1994). The first level is represented by the main goal. It can become more detailed by using sub-goals. Sub-goals are placed in the second level. For example, in a case study on an highway, the main goal is: the minimisation of highway impact; sub-goals can be: the minimisation of impact on the environment, on monuments, on public health, on the economy. Each of these elements is then described by other factors on a third level. This procedure can be further developed until a reasonable degree of detail is attained. At the bottom of the hierarchy the elements to be judged are placed.

In the second step, the analyst is asked to judge the elements in the same level of the hierarchy in pairs as to their relative importance. The way of comparing them is very simple as it is in the form of a question type: 'how much more important (or preferred) is element A compared to element B, with respect to some property'. The property is a sub-goal (or a factor) on the above level. For simplicity, this importance is relative and expressed in the form of verbal judgement. In such a way, the analyst does not need to have an overview of all the criteria (which, sometimes, are numerous) and to adjust all the judgements at the end of the procedure.

The third step is the procedure of weighting and combining all the priorities through the model. Synthesis from the goal node multiplies the weight of each parent node times the local priorities of its children nodes and of those children times the local priorities of their children. This process continues down to and including the alternatives. This procedure converts all the local priorities into global priorities throughout the model, the object being to obtain global weights for the alternatives. The global weights for each alternative are summed to obtain its final synthesised weight, or overall priority. If the

criteria are ‘goods’, i.e. have positive value, the more the weight, the best is the choice option. There are two main ways of synthesising: using the Ideal mode, the best choice is the top alternative, and the others are irrelevant. Using the Distributive mode, all of the alternatives are prioritised and their weights are meaningful. However, qualitatively, the two modes lead to similar results.

Finally, sensitivity analysis can be performed in order to test the results. This is a technique for testing outcome of a multi criteria decision model. In particular, it verifies any possible change of the final score compared to a variation in the criteria choice and its priority rank. In addition, it can be used to find any possible mistake by computing the final scores with many different methodologies. The most common methods for testing results are three:

- 1) Weight sensitivity: different priorities are assigned to the criteria
- 2) Impact sensitivity: choice-options are assessed differently.
- 3) Method sensitivity: different aggregating and/or standardising functions are applied to the same data.

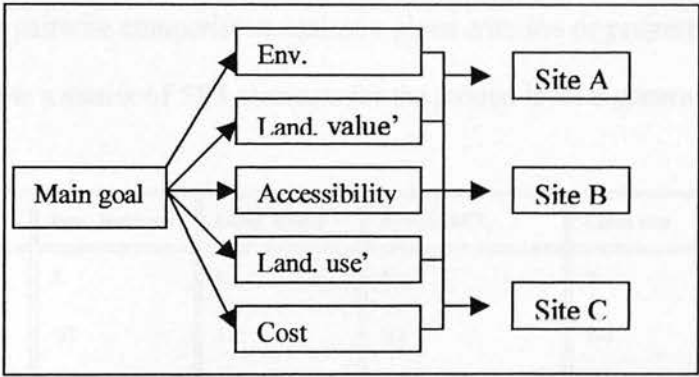


Figure 21: the hierarchy (example)

In the following hypothetical example, a local authority faces a problem of selecting a site for a residential development in a region with particular environmental values. In order to use the AHP method, the decision problem must be structured into a hierarchy where-in the elements of the problem are ordered according to their relationships. The analyst, therefore, in conjunction with all the involved parties (local population,

environmentalists, etc.), pre-selects choice options and defines relevant criteria for making the decision. Assuming he identifies three possible locations (A, B, C) and criteria ('environmental features', 'landscape value', 'accessibility', 'land use' and 'cost') these elements are then ordered into the hierarchy: the main goal – 'to select an optimal site for residential development' - is placed at the top. The criteria are in the intermediate levels of the hierarchy. At the lowest level are the alternatives to be evaluated (figure 21). Following this phase, the analyst (and all the players) determines the relative importance of the criteria and the choice options. The judgements are made by using the pair-wise comparison method, i.e. the element at a given level is taken as a common_property or criterion for pair-wise comparison of its child elements at the next lower level of the hierarchy. For example, regarding 'environmental features', he must compare_locations A with B, A with C and B with C. Each time he assesses which one is considered more favourable under this criterion and how much more so. To do so, the AHP uses the Saaty scale (see table 3 page 51), where verbal judgements correspond to rates. This process usually starts from the top of the hierarchy and is repeated for all the elements in each level. As the pairwise comparisons against a given criterion or property result in a matrix, in this example a matrix of 5X5 elements for the second level is generated (table 2).

	Env. features	Land. Value	Accessibility	Land use	Cost
Env. features	1	6	4	2	3
Land. Value	1/6	1	1/2	1/3	1/2
Accessibility	1/4	2	1	1/2	1/2
Land use	1/2	3	2	1	2
Cost	1/3	2	2	1/2	1

Table 2: the evaluation matrix (example).

This matrix corresponds to the judgements obtained by comparing the elements in the

left-hand column with the elements in the top row. As a consequence, they are symmetrical, i.e. judgements in the upper triangular part of a matrix are opposite those in the lower triangular part. In addition, when comparing one element with itself, the comparison must give 1 and the diagonal values are always one. Table 2 is the matrix of the five criteria.

A further five similar matrices (of 3x3 elements) are created for the last level. Once these matrices are generated, the AHP derives the weights for the criteria by solving the principal eigenvector of the matrix and then normalising the result. These weights are called 'local' since they are referred to a particular criterion or property and not the main goal. After they have been multiplied by the weight of their parent element (or criterion), they are called global weights. This process is called 'synthesis' and results in a set of priorities for the locations, where the higher is the score, the most preferable is the alternative. In this example, site A - with the highest overall weight – is the best location for this use. As already mentioned, the AHP also measures the rationality of judgements by means of a 'consistency ratio'. When this ratio exceeds 0.10, the judgements often need re-examination. However, the consistency ratio in this example is 0.004.

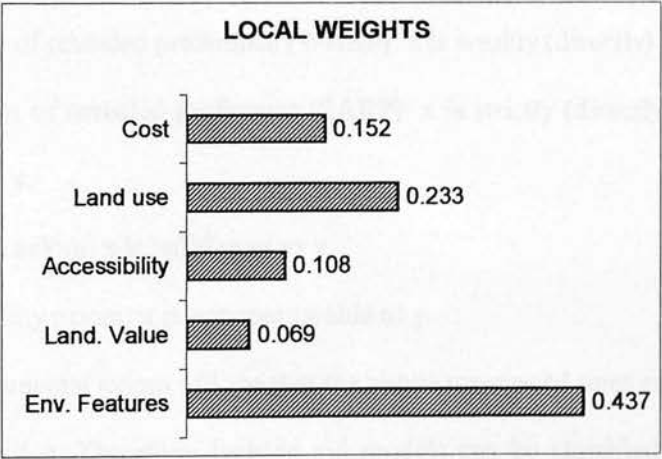


Figure 22: criteria's weights (example)

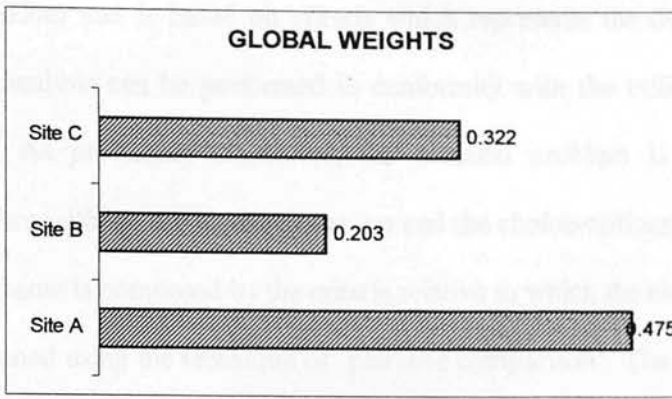


Figure 23: results(example)

3.3. The AHP model in detail

In detail, this model and the relative logic principles are much more complex. Any decision aid model is composed of a schematic representation of the real world and of a precise decision procedure, generally based on axioms. Firstly, the analyst structures the decision problem according to the model to be used. Then the problem is analysed through the model, which estimates pros and cons of every option, so that it is possible to make a decision in accordance with the decision maker's goals. Generally speaking, the most important decision axioms are:

- 1) weak axiom of revealed preference (WARP): x is weakly (directly) preferred to y .
- 2) strong axiom of revealed preference (SARP): x is strictly (directly and indirectly) preferred to y .
- 3) Indifference axiom: x is indifferent to y .
- 4) Incompatibility axiom: x is not comparable to y .

However, the fundamental axiom affirms that the above mentioned ones are indispensable and mutually exclusive. Therefore decision aid models can be classified into two wide groups, those that are 'descriptive' and those 'prescriptive', depending on whether they respect the fundamental axiom or not (e.g. the axioms are mutually exclusive or not).

The AHP model is a multi criteria decision model of the second group: it respects

the fundamental axiom and is based on criteria which represents the decision maker's goals so that the analysis can be performed in conformity with the utility theory – the more, the better. As previously mentioned, the decision problem is arranged in a hierarchical structure with the main goal on the top and the choice-options on the bottom. The core of the scheme is composed by the criteria relative to which the evaluation (or the decision) is performed using the technique of 'pairwise comparison'. The purpose of this is to determine the contribution of each factor to the main goal. Due to the fact that people are not able to express absolute judgments, this contribution is derived through the index of dominance of each factor relative to the others - $a_{ij} = w_i / w_j$ - by using a particular ratio scale that is both verbal and numerical - the Saaty Scale (table 3). One element dominating another simply means that the first is more important (or effective) than the other and this can be measured by dividing the importance of the first by that of the second.

Intensity	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgement numerically
rational: 1,5 etc.	For tied activities	When elements are close and nearly indistinguishable
fractions: 1/5, etc.	Reciprocal values	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit

Table 3: the Saaty scale

Given n criteria, the number of pair wise comparisons is: $[n(n-1)/2]$, since the symmetric relationship² $a_{ij}= 1/a_j$ must hold. For example, if we consider four criteria, the comparisons are 6, which correspond to the number of elements within the upper triangular part of the symmetric matrix crossing the four criteria (see figure 24).

A_1	A_2	A_3	A_4	
1	$A_{1,2}$	$A_{1,3}$	$A_{1,4}$	A_1
$A_{2,1}$	1	$A_{2,3}$	$A_{2,4}$	A_2
$A_{3,1}$	$A_{3,2}$	1	$A_{3,4}$	A_3
$A_{4,1}$	$A_{4,2}$	$A_{4,3}$	1	A_4

Figure 24: example of a hypothetical symmetrical matrix A of four criteria. The numbers in the upper triangular part are the opposite of those in the lower triangular part.

Then all these values - placed into the matrix A - are aggregated and standardized into a vector. There are many different ways of standardizing vector; however, the most common are the distributive mode and the ideal one. The former is appropriate for evaluating the priority of each option relative to all others: each value is divided by the row sum. The second one emphasizes the importance of the best alternative, independently from the others, e.g. each score is divided by the best row score. The resulting vector W is usually called ‘vector of local priorities’, because it measures the relative importance of the criteria generating the matrix A . It is easy to verify that W is the eigenvector associated to the eigenvalue n of the matrix A : $[A \times W = nW]$, called fundamental equation. Generally speaking, it can be said that the matrix of the comparisons is proportional to the local priorities for a particular vector W (the eigenvector) and a particular value n (the eigenvalue) associated to the matrix.

² It ensures the rationality of the judgments

In detail, the following fundamental equation

$$\begin{vmatrix} w_1/w_1 & \dots & w_1/w_j \\ & \dots & \\ w_i/w_1 & \dots & w_i/w_j \end{vmatrix} \times \begin{vmatrix} w_1 \\ \dots \\ w_j \end{vmatrix} = n \begin{vmatrix} w_1 \\ \dots \\ w_i \end{vmatrix}$$

is equal to a group of generic equations of the type:

$$\begin{cases} a_1 x_1 + \dots + a_j x_j = y_1 \\ \dots \\ a_1 x_1 + \dots + a_j x_j = y_n \end{cases}$$

where w_1/w_j is equal to a_j , x_j is w_j and the roots are the local priorities. The computation of these equations is simple as each row of the matrix is a linear transformation of the previous one. However, the value a_{ij} ($=w_i / w_j$) is mainly approximated, since w_i and w_j are not completely known. In other words, the more accurate the estimation is, the more n converges to the maximum eigenvalue λ_{max} . so that $A \times W$ is equal to nW .

Therefore:

- 1) the fundamental equation can be resolved if λ_{max} is introduced: $A \times W = \lambda_{max} W$
- 2) the matrix A is consistent if $n = \lambda_{max}$; however, usually it is $n < \lambda_{max}$, since the transitivity axiom is seldom violated³.

Saaty has developed a method for controlling the consistency of his model: the 'Consistency Index' $CI = (\lambda_{max} - n) / (n - 1)$ - the variance of the error, referred to n ⁴ - and the 'Consistency Ratio' CR which is obtained by dividing the appropriate CI by the average CI value derived from random generated matrices of n size. Saaty suggests that a vector

³ The transitivity ensures that $a_{ij} = a_{ik} \times a_{kj}$.

⁴ Roughly speaking, this is a method for measuring the difference between λ_{max} and n , standardised with respect to n .

may be accepted if $CR \leq 0.1$, tolerated if $0.1 < CR < 0.2$ and rejected if $CR > 0.2$ (Saaty 1995, Saaty 1996).

4. APPROACHING THE PROBLEM

4.1. Introduction to the case study area

The case study area is located in the "Veneto" region, northeast Italy, and specifically on the Venice lagoon. This region is 18,377 km² wide, with about 4,362,000 inhabitants (237 people per km²) who mainly live in the "Padana" valley, a wide sedimentary plateau created by the "Po" river (the largest in Italy), and partially by the "Adige" and "Brenta" rivers. All these rivers flow into the upper Adriatic Sea directly or through the lagoon.

This lagoon is the largest in Italy, about 550 km² extending from "Brenta" mouth, close to the town of "Chioggia" to the south, to the "Piave" river to the north. However, its terrain embraces a wider area including the surrounding dry land, about 1,900 km², which conveys rain and river water to it. This territory is shared by three different provinces – Venice, Treviso and Padua – with a total of 1,460,000 inhabitants (in 1991) in one hundred and one towns and villages. Part of them (173,000) live in the coastal barriers¹ and the islands, which cover a terrain surface of 40 km², including the historical centre of Venice – about 70,000 people. Fish farms and salt marshes² cover a surface of 92 km² and 47 km², respectively.

Generally speaking, this region is one of the richest in Italy, because of the textile industries near Vicenza and Verona, the Porto Marghera industrial estate and the intensive cultivation of tobacco and sugar beet throughout the valley.

¹ Coastal barrier are very narrow islands and littorals separating the inner water from the sea. Part of them is artificial and their construction originates from the need to defend the residential settlements. The first traditional ones were built in wood (6th century); however, the most famous are probably the "murazzi", rough, stoned walls built in the 18th century.

² Fish farms are wetlands close to the lagoon but separated from it by embankments, which defend them from flow and ebb tide. They are traditionally used for fish breeding and hunting. Salt marshes are wet areas within the lagoon, but solid and partially covered by vegetation. Their importance is relevant for two reasons, at least: for their ecological and biological values (they host many different organic, vegetable and bacterial matter and a wide variety of birds) and for their important role in regulating the lagoon hydrodynamics.



Figure 25 airborne photograph of the Venice Lagoon and the study case area - the red rectangle (Comune di Venezia, 1996).

The local economy is mainly based on tourists visiting Venice and the industrial activities in Porto Marghera; fishing is also an important activity for many people, in particular in the municipality of Chioggia (southern boundary of the lagoon). In addition, 52% of the total dry area is devoted to agriculture and breeding, with about 230,000 livestock.

The rail and road networks of the Venice lagoon district are respectively 302 km and 4,108 km wide. The water network is about 2,500 km long; however, it also includes the deep maritime 'canals' within the lagoon, which allows the large oil tankers to reach the industrial harbour, as the mean depth of the lagoon is only 1.2 meter, and many areas are just few centimetres deep.

4.2. The history of the case study area

The history of the Porto Marghera area is very recent, compared to that of the Venice lagoon one, which, indeed, was first inhabited in the early fifth century by people who found in these islands a valid refuge from the first barbarian invasions of Italy³.

The commercial harbour of Porto Marghera was first set-up in 1904 as a place dedicated to local activity only. The first proposition regarding an industrial and commercial harbour in this place was officially made in 1902. However, it must be taken into account that the commercial port of Venice had been already moved from the S. Marco Basin to San Basilio and Santa Marta, in an inner location relative to the Adriatic sea (Lido and Malamocco canals), and facing the Marghera coastline and the mainland. It was probably the first symptom of the growing necessity for an important regional port structure.

³ Due to its immensity, the history of Venice and its territory is omitted. Information on it can be read in specific books or more concisely in any valid tourist guide.

The first official development program was set-up in 1917. This program included the development of commercial maritime activity and the establishment of a new industrial port, which should have balanced the huge economic activity of northwest Italy - mainly car and metallurgical industries in Milan, Turin and Genoa.

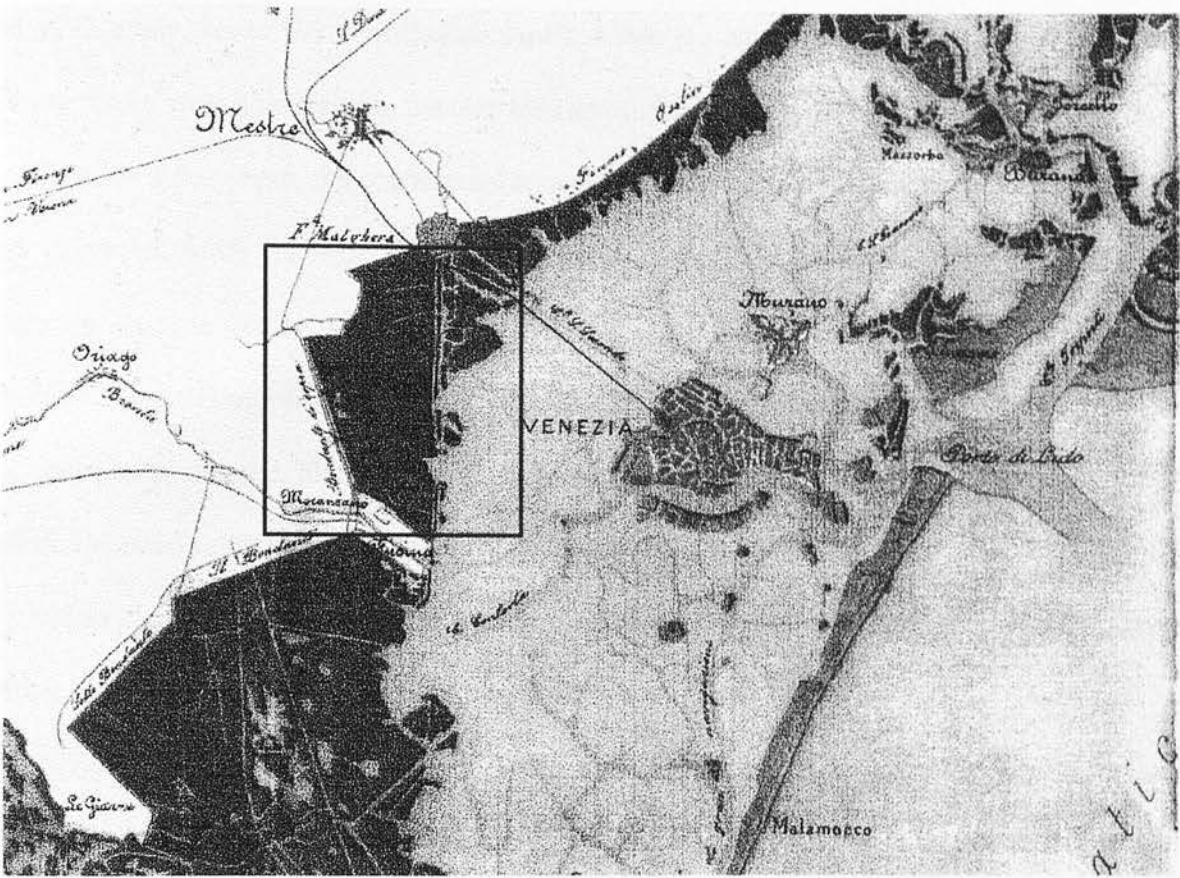


Figure 26: the study case area in 1920 (P. Colombo 2001).

The most important architect of this plan was Count Volpi, a venetian nobleman famous for conceiving the Venice International Film Festival, the Ciga network hotel. Moreover, he was the main shareholder of the most important Italian power supply enterprise, which was been supplying energy to the state until few years ago⁴. His main goal

⁴ It is a common idea that Mr. Volpi did not take very much into consideration any environmental matter. As a matter of fact, his power company was responsible for the Vajont disaster in 1964. One of the highest and robust dykes in Europe was built at the bottom of Vajont valley, close to the town of Longarone, to produce hydroelectric energy. However, the managers and the shareholders didn't take into account the geologists'

was to concentrate metallurgical industries, chemicals and petrol refineries in one area close to the sea in order to profit from the low cost raw material, coming from abroad via the Adriatic Sea. In 1920, the “Società Porto Industriale” was established, the first company dedicated to building the main infrastructures to be used by future industries. Between 1919 and 1922 many works were concluded: canals within the lagoon were excavated, roads and railway tracks were positioned in the new area and the urbanisation was almost completed.

After a few years, the commercial area was enlarged again and the construction of the first industrial estate (named “Prima Zona Industriale”, ‘First Industrial Zone’) began and lasted for about ten years. The first industries were located there – carpentry, mechanical and maritime construction companies, a few crude oil deposits and one refinery– which treated raw and cheap material, like coal, sulphuric acid, chemical fertilisers, phosphates etc. In that period, the need to improve the urban set of this territory was also perceived, which led to the first urban plan of the Marghera and Mestre district, and the realisation of a new road-bridge linking Venice to the mainland, along the existing railway one.

Between the thirties and the forties, new industries were placed in the area, in particular those related to light alloys (i.e. those without iron) like aluminium and zinc, and one of the most important factories producing synthetic ammonia from coal gas in Italy. Besides, many others minor ones such as food, drink (including a brewery), lenses (optical) and fragrance plants, one power plant and many services and transportation activities raised rapidly to support these industries. At that time, the estate occupied a surface of about five hundred hectares and the number of workers was 17,300 (an increase of more than 300% compared to the early thirties!). The District Council proposed two development plans for

alarming report on the possibility of a landslide. This actually happened suddenly producing a huge overflow, which destroyed the town completely and killed most of the inhabitants.



Despite the fact that the Italian economy had a tragic break during the Second World War, when many plants were destroyed, the local industrialists' demands for more space increased between 1945 and 1955. As a result, in 1953 the plan for a new developing area ("Seconda Zona Industriale", the 'Second Industrial Zone') was approved along with the project of a new canal linking Malamocco to Porto Marghera⁵, in order to avoid the oil tankers passing close to Venice. Other new industries were established here: petrol-chemicals, refineries for crude and food oil, metal joineries and new power plants. The number of firms doubled and the employees reached 25,300 units in 1955. However, it has to be said that this number is probably smaller than the real one, as the occupational data did not included the workers employed outside the industrial area but depending on these activities. In addition, the residents in Mestre and Marghera increased significantly: respectively, from 20,000 to 50,000 and from 5,000 to 25,000, between 1920 and 1950. Globally, the district registered an increment of about 100,000 people.

In 1956, a competition was inaugurated for the conception of the General Master Plan of the Venice District, which in reality embraced the Marghera and Mestre settlements, too. The relevant minister approved this plan in 1962. However, the situation in Porto Marghera had already changed. At this date, there were already two hundred firms, including engineering companies, steel and ceramic industries; the employed people were about 30,000; the tons of products worked and sent away increased from seven to twenty five million, from 1960 to 1974. In spite of this optimistic data, the economic development of the area was worse than expected; consequently, a new industrial zone (the third one) was not realised even if its plan had been already approved in 1963 and a new dockyard (san Leonardo) had been built for petrol-chemical tankers.

⁵ Malamocco is a small town on the coastal barriers, which gives its name to the most important maritime access to the lagoon.

<i>Year</i>	<i>No. firms</i>	<i>Employees</i>	<i>Maritime traffic (ton x 1000)</i>			<i>Railway traffic (ton x 1000)</i>
			<i>Petroleum derived products</i>	<i>Others</i>	<i>Total</i>	<i>Total</i>
1920	11	?	?	?	?	57
1925	33	3,440	133	79	212	275
1930	73	5,100	514	310	824	671
1935	84	10,120	944	62	1,606	661
1940	95	17,300	1010	520	1,530	1,970
1945	103	15,700	33	126	159	65
1950	128	22,500	982	1,138	2,120	1,098
1955	172	25,300	1,815	3,350	5,165	1,334
1960	194	30,200	3,391	4,082	7,473	1,820
1965	229	32,980	4,756	6,345	11,101	1,413
1970	227	31,000	7,147	12,446	19,593	1,160
1975	228	30,680	6,132	12,230	18,593	1,127
1980	235	29,000	9,585	12,929	22,514	1,200
1985	260	23,000	9,301	12,031	21,332	1,200
1986	278	21,000	8,941	13,200	22,141	1,075
1987	298	20,677	9,883	12,221	22,104	900
1988	300	19,425	9,606	11,390	21,076	950
1989	301	18,708	6,577	11,438	21,015	995
1990	303	18,814	9,190	10,115	19,305	1,134
1991	298	18,708	9,119	10,751	19,870	1,155
1992	295	15,362	8,477	11,252	19,729	975
1993	289	14,705	7,903	10,485	18,387	910
1994	298	13,913	7,655	9,947	17,602	1,038
1995	295	14,028	8,707	10,389	19,096	1,406
1996	296	13,927	7,897	10,458	18,355	1,028

Table 4: historical data of Porto Marghera (? = data not available) (F. Candian 1998/99).

A new phase in the industrial estate's history had its origin in a national economic crisis of the seventies. From 1974 to 1989, the general trend was regressive: employment was reduced to the half of the previous data. The traffic of goods did not increase any longer and many minor activities closed down. Conversely, big companies were not particularly affected by this situation. Chemicals, petro-chemicals, metals, phosphate and fertiliser production still increased (see tables 4 and 5). This situation has continued to date, involving the cessation of activities related to agricultural products and a gradual regression of maritime and railway traffic of goods, in particular coal and raw food products, and the consequent reduction in employment.

years	plants	employees	harbour traffic	railway traffic
1935	84	10,120	1,606 tons	661 tons
1965	229	32,980	11,101 tons	1,413 tons
1995	295	14,028	19,096 tons	1,406 tons
1997	295	13,740	17,808 tons	1,028 tons

Table 5 : historical data concerning activities in Porto Marghera (F. Candian 1998/99).

4.3. Description of the industrial estate

Porto Marghera is recognised as being an important traffic crossroads, providing the central and eastern countries in Europe with an easy access to the sea. Its strategic position is validated by the proximity to the east-west European railway and highway networks as well as to the international airport of 'Marco Polo'.

The estate is a wide trapezium shaped industrial area (about 2,000 hectares), located between the outskirts of Marghera and the Venice Lagoon, at the bottom of the "Ponte della Libertà" ('Freedom Bridge'), connecting Venice to the mainland. The highway and the

railway from Venice to the north, the residential area of Marghera to the west, the “Naviglio Brenta” canal and the “Macontenta” municipality to the south delimit it.

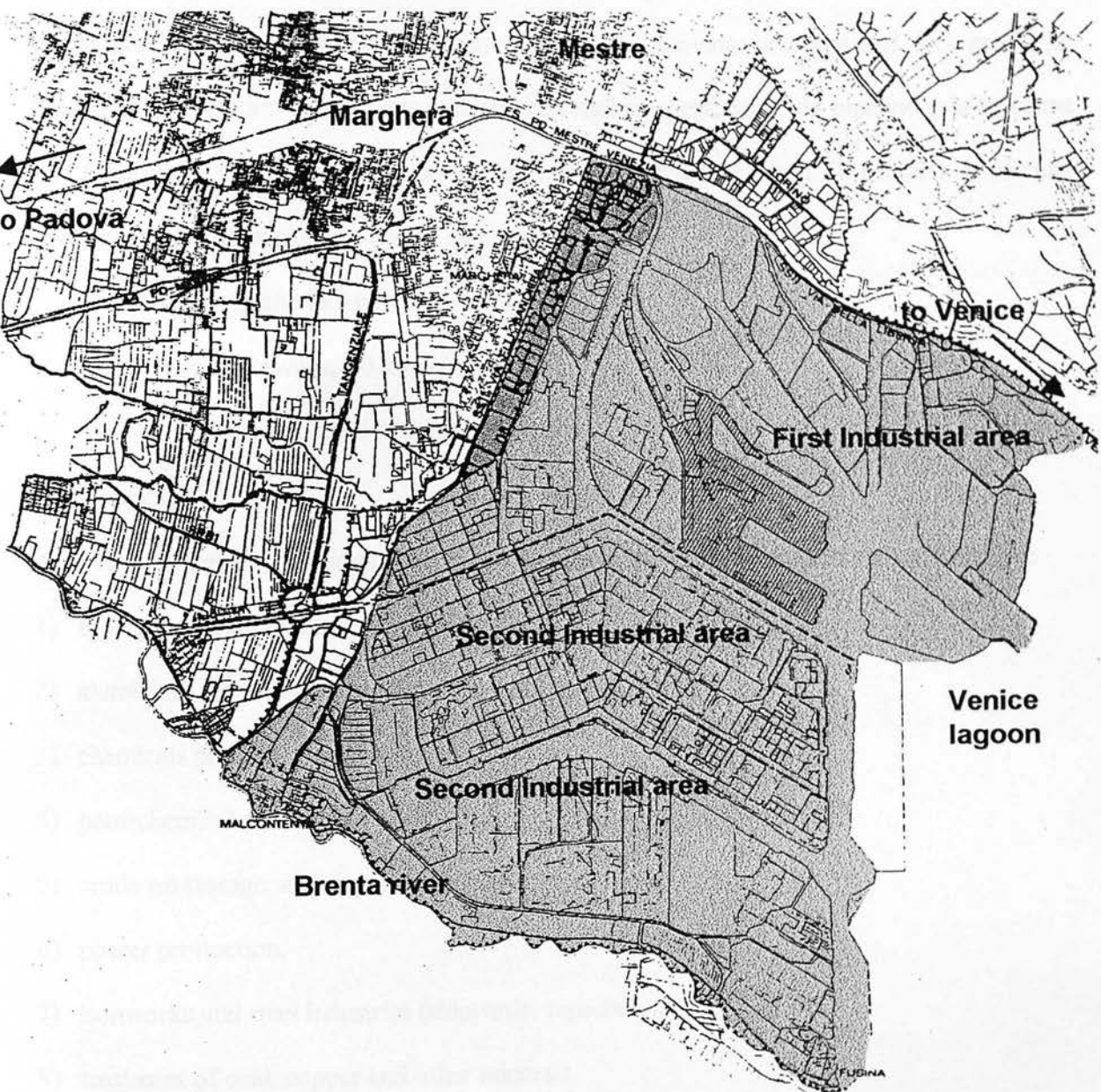


Figure 28: the study case area

The area embraces the industrial estate proper, 1,400 hectares wide (divided into “First Industrial Zone “ and “Second Industrial Zone”), the commercial harbour (120 hectares) plus canals and basins (340 hectares), part of the Venice Lagoon, and the inner traffic and railway network (80 hectares), used for moving raw material and products. Indeed, transportation of products and raw material are performed via pipeline (via Ravenna and Mantova,). In addition, it must be taken into account that about 40 hectares is of state ownership. The infrastructure can be summarised into:

- maritime canals, 18 km;
- inner road network, 40 km;
- inner railway network, 135 km;
- quays, 1.3 km.

At present, there are 295 firms, with 13,740 employees. The most important activities are:

- 1) food production (including fodder),
- 2) aluminium and other light alloys productions and works,
- 3) chemicals production and treatment,
- 4) petrochemical industries,
- 5) crude oil storage and deposits,
- 6) power production,
- 7) ironworks and steel industries (shipyards, especially),
- 8) treatment of coal, copper and other minerals.

They are distributed across the area in accordance with the historical zoning, i.e. I zone, II zone and the commercial port. Since the only two chemical firms in the first zone were closed in 1997, chemicals are mainly in the second zone, between the Southern Industrial Canal and the western one, next to the commercial harbour. Maritime construction activities

are still in their traditional location, in the first zone facing the Northern Industrial Canal. Petrol and crude oil deposits are mainly in the eastern part of the first zone ("Isola dei Petroli", 'Petrol Island'), with the exception of a few small deposits and related petrol-chemical activities in the second zone. Aluminium production and works are present in many different locations of the area; however, a concentration of these activities can be found along "Via dell'Elettronica" ('Electronics Street'), the Southern part of Porto Marghera. In this area, a power plant is also present. At present, there is only one large food production firm in the first zone. The narrow strip of territory between the southern boundary and "Via dell'Elettronica", where aluminium production activities and power plants are, is practically empty, with the exception of a dump. Other minor waste material disposal areas are in the second zone and within the commercial port precinct. The western area, between "Via dell'Elettricità" ('Electricity Street') and outskirts of Marghera, is dedicated to general offices and services.

The main access routes to the industrial estate are through Malcontenta town, "Via dell'Elettricità» and "Via dell'Elettronica", from the south, and "Via della Libertà" ('Freedom Street') from the north, where the highway passes through.

4.4. Description of the harbour

Many parts of the lagoon are under the jurisdiction of the Venice Port Authority: the commercial harbour in the First Industrial area (named 'Insula'), the San Leonardo harbour at the southern edge of the lagoon (for oil tank use only), the tourist harbour within the Venice city centre and other small tourist piers. In addition, the Authority is responsible for access to the lagoon, the main navigation canals and the spaces in front of every pier.

Data collected in 1997 shows that every year 80% of the traffic is related to the harbour; in particular, 32.2% of the harbour activity refers to large ships (more than 10,000

tons). The number of oil tankers approaching the harbour has been quite constant so that it represents the main activity. Many people are involved in port activities – indeed, 9,000 people work in the commercial harbour zone, being 65.5% of the population of the case study area. In addition to these, about 8,000 people work in minor activities connected to the port. Most of the raw materials arrive to the industrial pole of Marghera via ship (18,300,000 tons per year), while final goods are mainly sent away via track and railway (1,500,000 tons per year and 11,000,000 tons per year, respectively). It is interesting to note the difference between the amount of incoming material and that of outgoing one: in fact, many industries transform, stock and retail the material within the industrial area (tables 6 and 7).

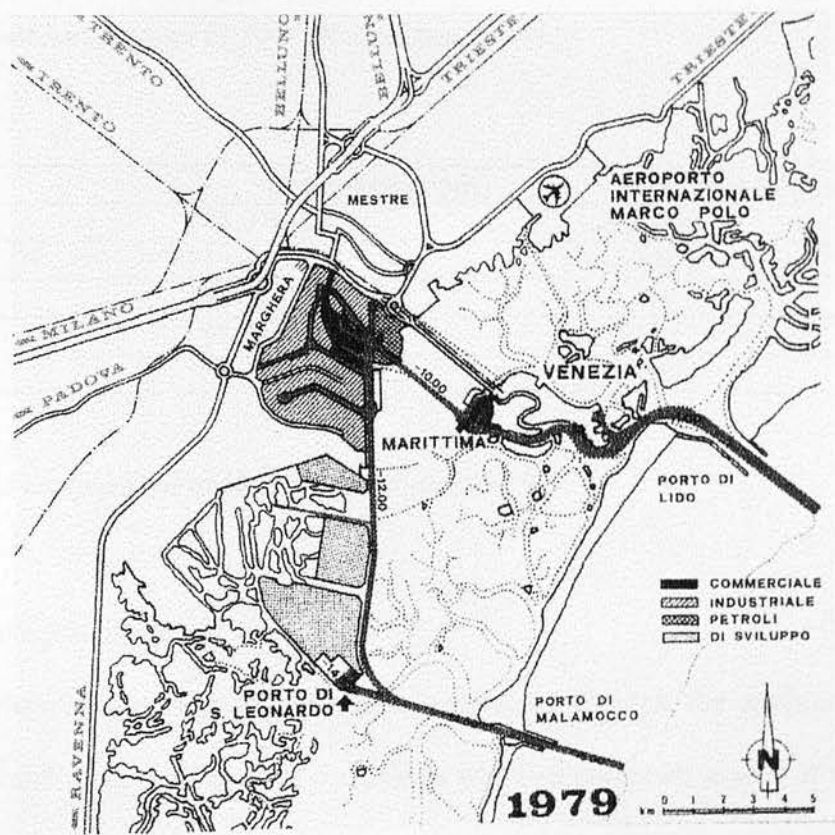


Figure 29: the main maritime accesses to the study case area (P. Colombo 2001).

petroleum substances	%	others	%
petrol, naphtha, paraffin	23.7	cereals	11.4
diesel oil	15.9	oil seeds	2.4
combustible oil	9.5	different types of flour	6.3
other petroleum substances	0.4	solid fuels	17.8
crude oils	50.6	minerals	13
		fertilisers and phosphate	8.5
		chemicals	24.5
		scraps iron and steelworks products	10.3
		others	5.6

Table 6: product percentages in 1997 (F. Candian 1998/99).

	in (tons of goods)	out (tons of goods)
ship	16,026,436	1,781,509
track	1,646,890	9,129,862
railway	387,603	640,919
fluvial ship	131,894	47,521
pipeline	0	3,483,875

Table 7: traffic composition in 1997 (F. Candian 1998/99).

4.5. Urban management means

The urban management of the area is conducted through the application of many different plans and programs. Each of them deals with one particular aspect of the zone or a different level of control (e.g. regional, local, etc.). These instruments are:

1. PTRC Piano Territoriale Regionale di Coordinamento (Regional Co-ordination Plan for the Territory);

2. PALAV Piano di Area della Laguna e dell'Area di Venezia (Plan of the Lagoon and the Venice area);
3. PRS Programma Regionale di Sviluppo (Regional Developing Program);
4. PRT Piano Regionale dei Trasporti (Regional Plan for Transportation Means);
5. PRG (District Master Plan).

In addition to these, three more instruments are particularly relevant for this study.

- a) the New Master Plan for Porto Marghera,
- b) the General Agreement on Chemical Hazard Mitigation Actions,
- c) the PRP Piano Regolatore Portuale (the Port Master Plan).

4.6. Opportunities and constraints

Due to its optimal location, the estate of Porto Marghera and its harbour is one of the most important industrial sites in Italy and in central Europe as well. It is located in a wide flat land in the Veneto Region, close to the highways and railways going to Milano, Torino, Bologna, Trieste and also to France, Austria, Germany, and Eastern European nations. Furthermore, it is easily accessible through the Adriatic Sea – very quiet water.

However, it suffers from many different problems. Critical problems arise from the type of industries and the organisation of the area. Due to their size and the amount of treated substances, chemical and petrol-chemical plants are the most important. The majority of the inflammable and explosive products (petroleum and other derived substances) are concentrated in the northern part of the area, close to the highway and the railway. The toxic chemicals, on the other hand, are produced in the Second Industrial area, with the exception of prussic acid treatment, which is located on a southern zone, near a commercial area. This concentration might be a problem in case of any accident because:

1. The industrial estate is very close to the residential areas of Marghera and Mestre. Any potential accident involving the hazard substances treated by the plants might have catastrophic results for the population.
2. The southern edge of the industrial estate - the Brenta river - and the lagoon have special naturalistic values. These areas are under the threat of an ecological disaster.

Employment data collected from 1965 to 1997 shows that small enterprises (less than 100 employees) are increasing (from 8.63% to 35.09%), while large ones (500 or more employees) are decreasing (from 75.26% to 37%). This element seems to mean that the character of the industrial estate is changing rapidly. It would imply that: many portions of the area will be dedicated to minor activities and services, increasing the population of the industrial estate. At the same time, the cessation of the activity of larger plants results in an availability of space, which need to be reclaimed

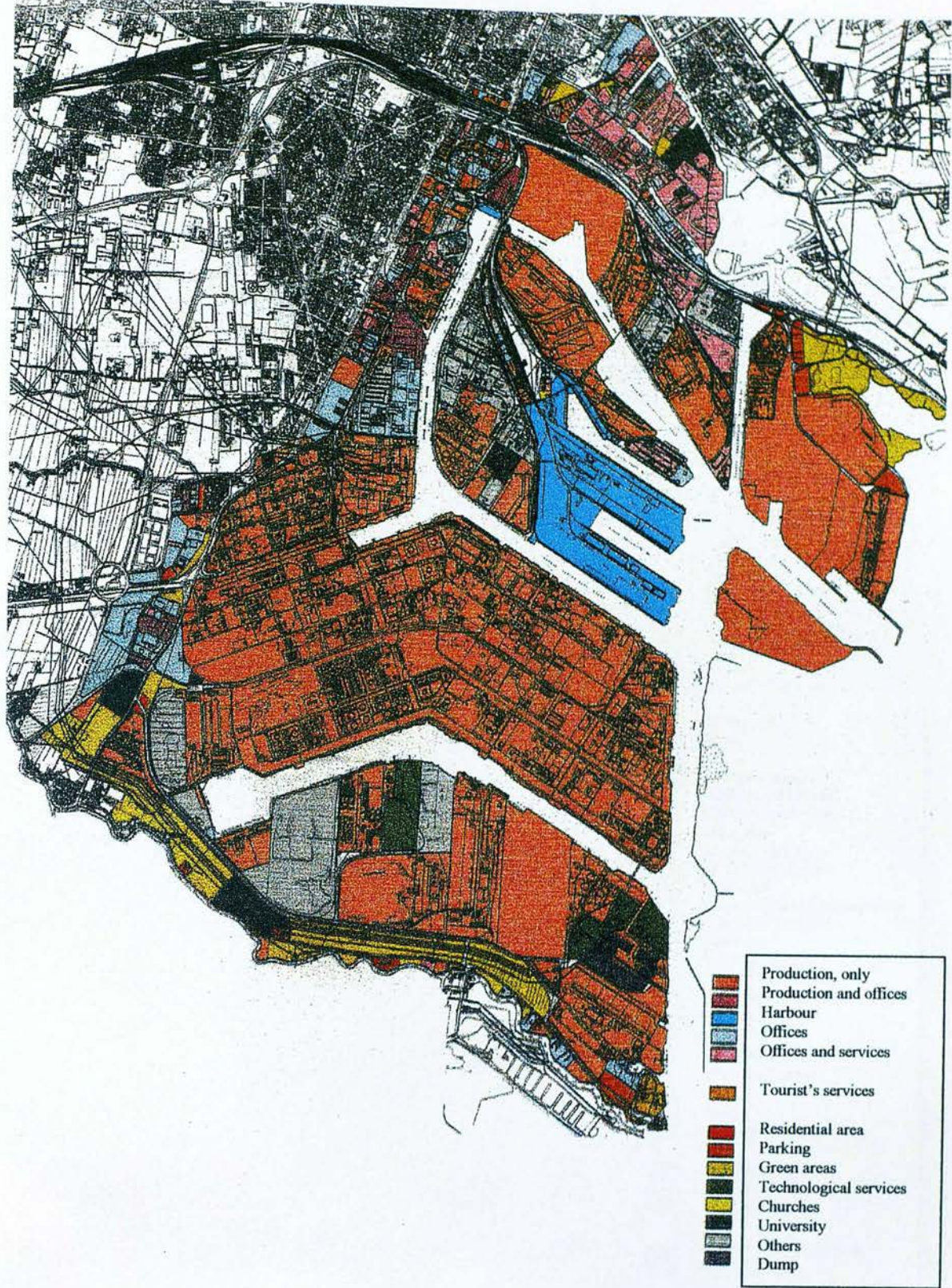


Figure 30: land uses of the study case area – study map of the Urban Plan Authority of Venice (Comune di Venezia 1996).

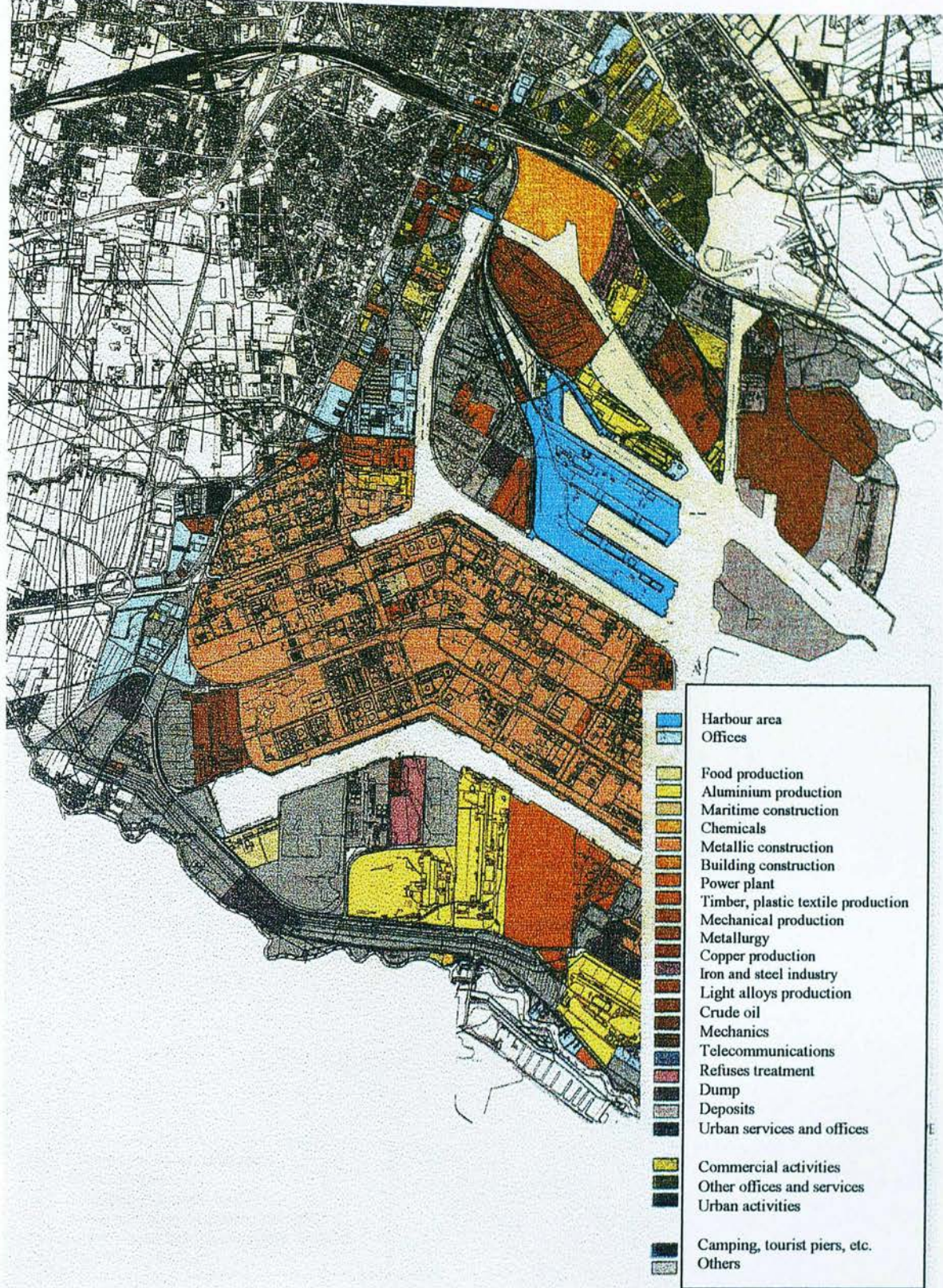


Figure 31: map of the activities in the study case area - study map of the Urban Plan Authority of Venice (Comune di Venezia 1996).



Figure 32: localisation of the empty areas – study map of the Urban Plan Authority of Venice
(Comune di Venezia 1996).

5.1. Italian Environmental Protection Agency's Risk Assessment on Porto Marghera

At the end of its analyses on Porto Marghera, the Italian EPA produced a set of maps (in Appendix B), which illustrated and summarised the type of information explained in the quantitative risk assessment section. Since most of them have been used as both the direct and indirect input for the experimental procedure (when direct data was not available to be input, the experts were asked to express their judgement on the base of the tables), these graphs are attached to this work. The following are some brief explanations on them.

Calculations and maps are based on information on: number, localisation and type of plants at risk of Major Accident, safety measures and possible incident scenarios indicated by the plants conductors in each Safety Report. Globally, 256 incident scenarios have been analysed. However, part of them considers both toxic substance release and fire/explosion scenarios, so that the total amount of scenarios is 323 (mostly fires and gas emissions). These plants are mapped in tables at the end of this chapter. Along with the plotting of Major Accident Hazard industries, circular areas of possible damage are marked on maps; the rays are those indicated by the plant conductors in the Safety Report regarding different incident scenarios and consequences. In general, toxic injury scenarios present larger areas; in particular, the widest damage area is that of the chlorine-soda plant of Enichem industry, about 4-kilometre diameter. This kind of information is found to be significant in terms of political and social management by the local and central authorities.

N°	Company	Activity	N° of plants	Classification	Type of risk	Location (zone)
1	3V CPM Spa	Chemical production	1	N	Fire, explosion, toxic emission	6
2	AGIP GAS Spa	Fuel deposit	-	N	Fire, explosion	2
3	AGIP PETROLI	Petrol refinery and deposit	n. a.	N	Fire, explosion, toxic emission	2
4	Geos Ambiente Spa	Industrial refuses treatment	1	D	Fire, explosion	5
5	API Spa	Fuel deposit	-	D	Fire, explosion	2
6	Ausimont Spa	Chemical production	3	N	Fire, explosion, toxic emission	5
7	Crion Srl	Technical gas production	n.a.	D	Fire, explosion	5
8	Decal Spa	Deposits and loading services	n.a.	N	Fire, explosion, toxic emission	6
9	Elf Atochem Spa	Chemical production	2	N	Fire, explosion, toxic emission	5
10	Enichem Spa	Chemical production and deposit	25	N	Fire, explosion, toxic emission	5
11	Eridania Spa	Food oil deposit	1	D	Fire, explosion	5
12	Esso Italiana Spa	Fuel deposit	n.a.	D	Fire, explosion	2
13	EVC Italia	Chemical production	2	N	Fire, explosion, toxic emission	5
14	IES Spa	Fuel deposit	-	N	Fire, explosion	4
15	Marghera Butadiene	Chemical production	1	N	Fire, explosion, toxic emission	5
16	Montefibre	Synthetic fibre production	3	N	Fire, explosion, toxic emission	5
17	San Marco Petroli	Fuel deposit	-	D	Fire, explosion	4
18	Sapio Srl	technical gas production and supply	n.a.	D	Fire, explosion	6
19	Servizi Costieri Srl	Industrial solvent recycle and treatment	1	D	Fire, explosion	2
20	SIMAR	Metallurgic industry	1	N	Fire, explosion	1

Table 8: industries at risk of Major Accident (Comune di Venezia 1996).

Legend: n.a. = not available; N= industry subject to notification; D= industry subject to declaration.

industry	Scenarios analysed in the Safety Report						
	events	toxicity	fire	uvce	explosion	bleve	tox vapour
3V CPM S.p.A.		6	10		1		
AGIP GAS S.p.A.			8	3		2	
AGIP PETROLI		7	30	8		4	
Ambiente S.p.A.			2	1			
API Anonima Petroli Italiana S.p.A.			5	2			
Ausimont S.p.A.		11	4				
CRION S.r.l.			2				
DECAL S.p.A.		6	11	9			
Elf Atochem S.p.A.		9	3				
ENICHEM S.p.A.		76	38	2		1	3
Eridania S.p.A.							
ESSO ITALIANA S.p.A.			5	3			
EVC Italia (CV22/23)		4	8				
EVC Italia (CV24/25)		3	7	2			
IES S.p.A.			4				
Marghera Butadiene		2					
MONTEFIBRE		9	4				2
San Marco Petroli		4					
Sapio S.r.l.							
Servizi Costieri S.r.l.		3	3				
SIMAR			1				
		140	145	30	1	7	5
							256

Table 9: incident scenarios analysed in the Safety Report and taken into account by the three experts. Note that fire¹ and toxicity are the most numerous scenarios (Italian EPA analysis).

The maps of ‘iso-risk’ sectors have been obtained by overlaying a grid to the study case area. The grid is composed of 1 kilometre side cell, which is again divided into 16 sub-cells of 250-metre side. Within the map of a particular incident scenario, each cell is associated to a weight, which results from the product between incident frequency and probability of a particular wind direction.

¹ Fire includes jet-fire, pool-fire, tank-fire and fireball. Bleve and uvce are particular types of explosion due to gas emission. See glossary for explanation.

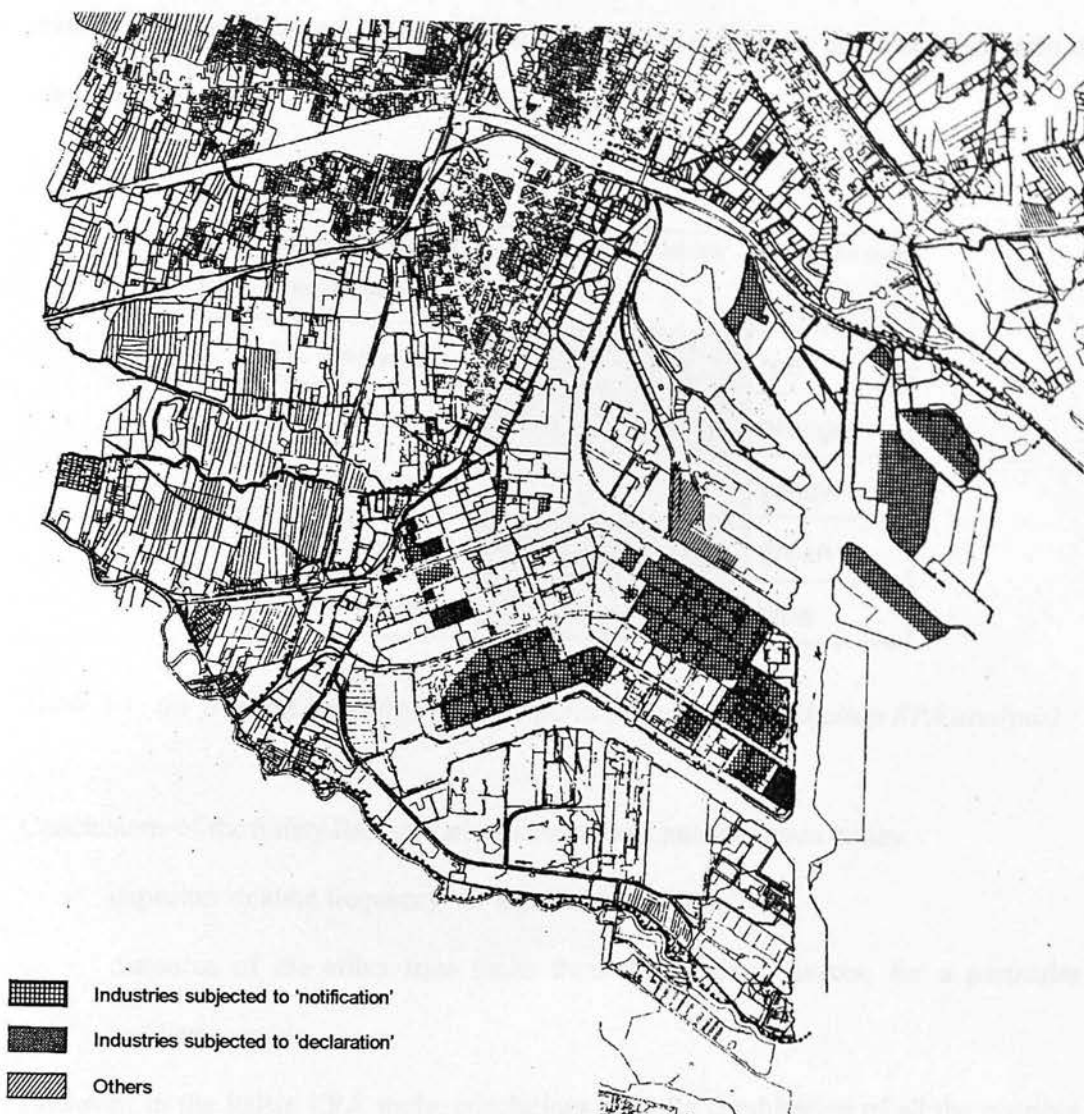


Figure 33: the location of industries subjected to 'notification' and 'declaration' (Comune di Venezia 1996).

Combinations of the all possible incident scenarios results in 'iso-risk' maps for fatality and injury which can be seen in the maps in Appendix B. Different colours correspond to five categories of risk in order to approximate 'iso-risk' contour and facilitate reading. The fatality map shows that any possible risk scenario is mainly confined within the industrial estate, not involving residential areas, with the exception of one plant (Elf-Atochem) close to Fratelli Bandiera street. Conversely, injuries may

involve portions of Mestre, Marghera and Malcontenta districts as the toxicity scenario is very wide.

Frequency order of magnitude	Associated colour	Description
1E-2 time/year	red	red
1E-3 time/year	orange	orange
1E-4 time/year	yellow	yellow
1E-5 time/year	green	green
1E-6 time/year	blue	blue

Table 10 : the five risk levels (referred to figures in Appendix B) (Italian EPA analysis)

Conclusions of the Safety Reports can be summarised into two main issues:

- expected incident frequency for a particular scenario,
- distances of the effect zone limits from the incident sources, for a particular incident scenario.

However, in the Italian EPA study, conclusions regard a combination of all the possible incident scenarios, both in terms of cumulative expected frequencies and F-N curves (Frequencies versus Number of potential fatalities). Thus, this data has been adopted to work out the present framework model for risk assessing, in particular in the first phase, when criteria and hierarchy have been developed on the basis of this information. In addition, experts and general public² have been requested to express their opinion on the basis of this information and graphs.

² In reality, population studied this data only partially as some graphs are strictly confidential and not available for publication; however, a full description of them was provided.

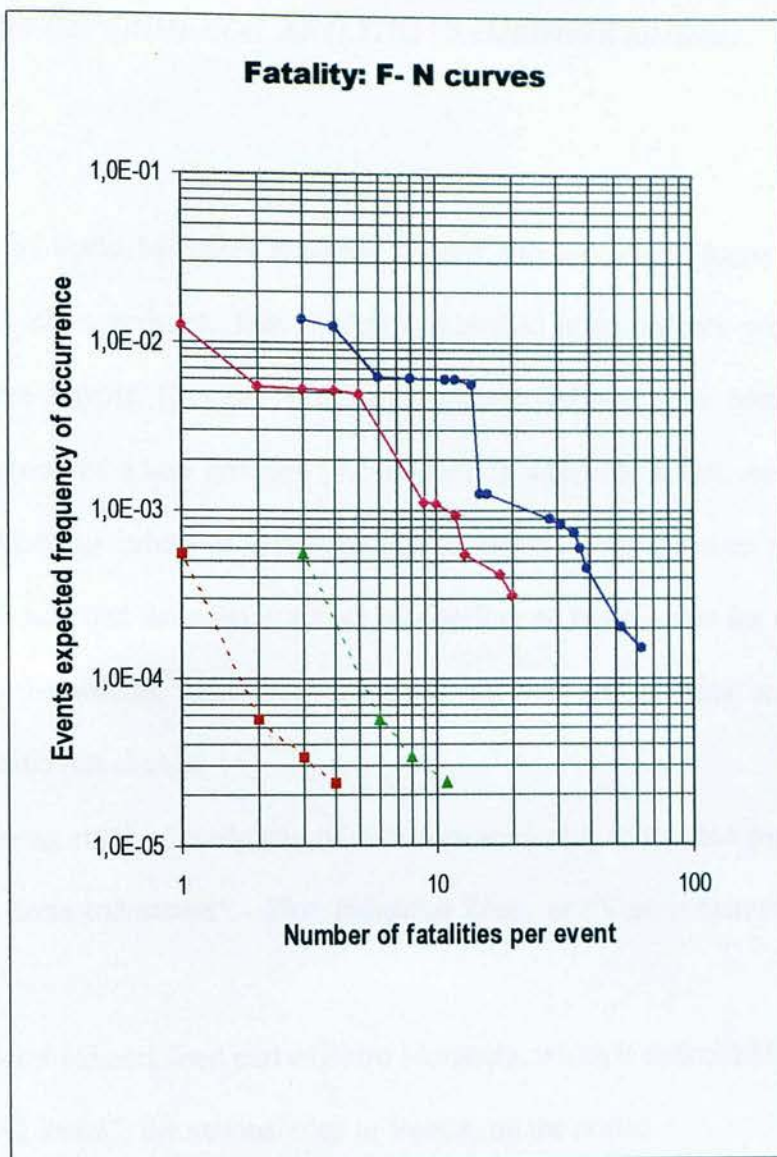


Figure 34: fatalities expressed in terms of expected frequency (F-N curves), which may occur in public spaces (including harbour area) (Italian EPA analysis).

- Dark blue line regards toxicity, fire and explosion, in daylight period,
- violet line regards toxicity, fire and explosion during night and weekends,
- green line regards fire and explosion during daylight period,
- red line regards fire and explosion during night and weekends.

6. APPLYING THE EXPERIMENTAL ANALYTIC FRAMEWORK MODEL

6.1. The zoning

The area of Porto Marghera has been divided into six zones (figure 35, page 86), according to their characteristics. This division was studied in accordance with the ARPAV staff and the three experts. However, the Port Authority did not agree completely on this layout, and has proposed a new partition (*APPENDIX I*), which is, in fact, not very different from the original one, as industries at relevant risk are again within the same zones. As a test of this, it must be said that the opinion survey was performed twice – one for each partition – in order to verify the possible variations, but the answers were still the same and therefore the assessment result did not change.

The following are the descriptions of each zone according to the first partition.

Zone 1: “Prima Zona Industriale” - First Industrial Zone, or “Venice Gateway for Science and Technology”.

It includes the oldest industrialised part of Porto Marghera, which is delimited by:

- “Via della Libertà”, the national road to Venice, on the north;
- The ‘Brentella’ canal on the east;
- The ‘Northern Industrial’ canal on the south;
- “Via della Pila” on the west.

Nowadays, the area is subject to many changes, as some disused areas are being already restored and turned into a technological centre – the “Venice Gateway for Science and Technology”. The main traffic network is organised around “via dell’Industria” (‘Industry Street’), which is the most important road through the zone. SIMAR – a metallurgical firm – is the only plant at risk of major hazard incident, in particular fire and explosion.

Zone 2: “Isola dei Petroli” - the petrol island.

This area includes the eastern part of Porto Marghera district, an island known as “Isola dei Petroli” (‘petrol island’) because of the activities on it. At the moment, it is almost completely occupied by crude oil and petrol deposits and refineries. As a consequence, all the firms in this area are at risk of fire and explosion:

- AGIP Petrol Spa (petrol refinery and deposits),
- AGIP Petroli Spa Venice refinery (petrol company),
- ESSO Italiana Spa (fuel deposits),
- AGIP Covengas Spa (fuel deposits),
- API Anonima Petroli Italia Spa (fuel deposit),
- IP, Italiana Petroli Spa (petrol company),
- Servizi Costieri Srl (industrial solvents treatment).

The present regional and district plans do not allow any different use of the area or any further increment of the present activities.

Zone 3: “Via Fratelli Bandiera”.

This area is a narrow strip of land between “Fratelli Bandiera” street (the Western boundary of the industrial estate) and “Via della Elettrocità”, the main road from south to north. Its upper limit is represented by “Via della Libertà”, “Via della Pila” (‘Battery Street’) and the dockyards on the Western Industrial Canal. Despite the fact that this zone is considered part of the industrial area, industries are not allowed at all, but offices, services and minor commercial activities, only. Therefore, no relevant hazard is present here.

Zone 4: the commercial harbour.

The commercial harbour is an island within the First Industrial Zone, delimited by the Northern Industrial Canal and the western one, and facing the lagoon on the east. This is the oldest original harbour, still used as a port, and therefore the road and rail networks are quite widespread in this area. Conversely, the activity is quite reduced now, so that part of the

island is disused; in addition, different activities are now present here: power plants, petrol deposits and ironworks and steel mills. Due to the fact that many of them are deposits, there is still the risk of fire, explosion and toxic substance emission. The firms subject to these hazards are:

- IES Spa, (hydrocarbon deposits),
- San Marco Petroli Spa (fuel deposits).

Zone 5: the “petrol-chemical” area

This area is delimited by “Via dell’Elettricità”, the Western Industrial Canal, “Via dell’Elettronica”, the Southern Industrial Canal and the lagoon. It is the core of the industrial estate, as its activity is the most traditional one and probably the most important in terms of local economy. The industries are mainly chemical, crude oil and petrol plants; therefore, the area is at high risk of fire/explosion and toxic substance emission. Firms at risk of Major Incidents are:

- Ambiente Spa (industrial refuses treatment),
- Ausimont (chemical industry),
- Enichem Spa (chemical industry),
- Montefibre (chemical industry),
- EVC Italia (PVC production),
- Marghera Butadiene Spa, (chemical industry)
- Elf Atochem (chemical industry),
- Crion Srl (liquid gas production),
- Eridania Spa (food deposit),

The main access and road network are represented by “Via dell’Elettricità”, and “Via della Chimica” (‘Chemistry Street’), respectively.

Zone 6: Fusina, Malcontenta and the southern boundary.

This zone includes the territory between “Via dell’Elettronica” and the Southern Industrial Canal, plus the fields below this road, along the “Naviglio Brenta” canal, which actually are shared with another municipality: Malcontenta. This fact is particularly relevant because of the closeness of the residential area of this municipality to industries at risk of fire/explosion and toxic substance emission. These industries are:

- Decal Spa, (stoking and loading services for petrol and chemical industries),
- 3 V CPM (chemical industry),
- Industrie Chimiche Barbini Spa (chemical industry),
- San Marco Petroli (petrol company),
- Sapiro srl (technical gas production and supply).

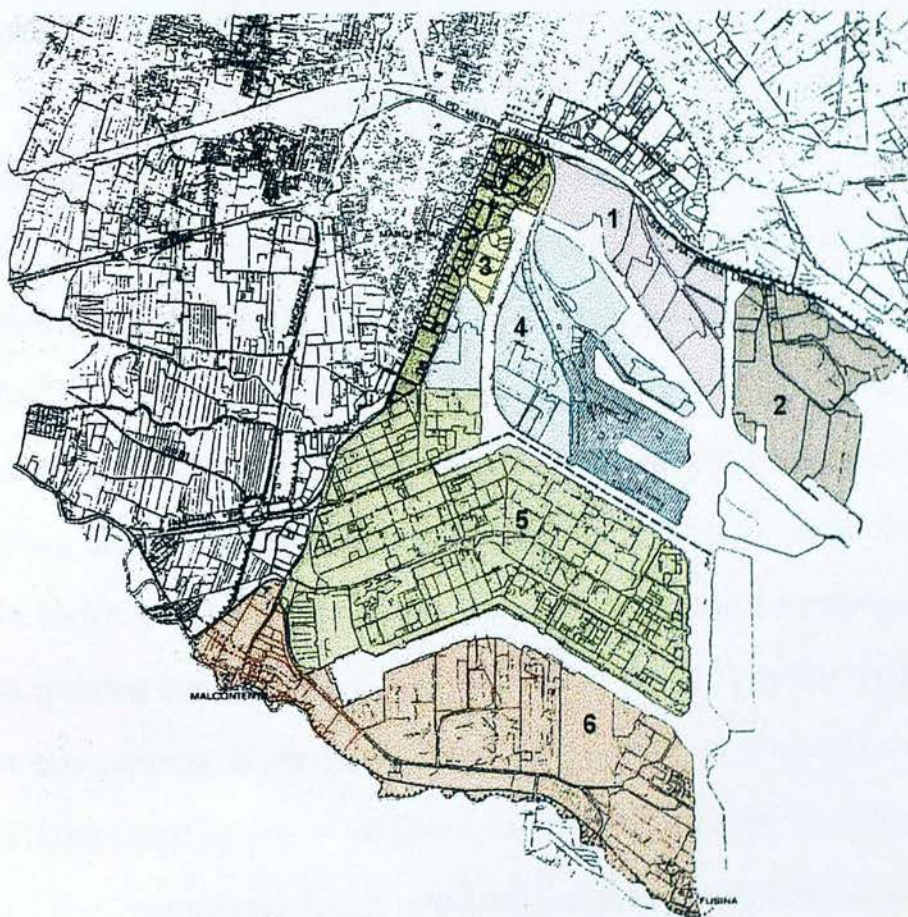


Figure 35: the zoning

6.2. *The scenarios*

As already mentioned, the scenarios considered in this study are the present situation and three other future developments:

- 1) The General Agreement on Chemical Hazard Mitigation Actions formulated by a scientific committee and stated in a document named "Program Agreement on Chemical Plants".
- 2) The new Master Plan for Marghera District, recently approved by the District Council.
- 3) A composite scenario resulting from alternative 2 plus alternative 3.

The following sections illustrate these three scenarios. However, a summary scheme can be found on page 96 (table 11).

6.2.1. The General Agreement on Chemical Hazard Mitigation Actions.

This is a short and long term risk reduction program (deadlines are respectively 1999/2000 and 2005) proposed by a general co-ordinating committee mainly composed of representatives of Porto Marghera industrialists, with the contribution of the Minister of the Environment and all the regional and local authorities. Its main goal is the rehabilitation of Porto Marghera and its transformation into an ecological industrial estate. This should essentially be performed following these three general tasks: a) general improvements in the railroad and maritime accessibility and internal raw and worked products transportation network; b) improvements in the plants safety measurements; c) dismantling and/or re-conversion of disused and partially in use plants, and reclamation of their sites. In addition to these, any possible measure reducing air, water and land pollution must be included due to regular plant emission, and land and canals reclamation in general.

In particular, the actions in each zone are:

Zone 1:

The dismantling of disused plants as well as of the rail-tracks used for petrol and crude oil transportation along “Via della Libertà”. Reclamation and safety improvements on the sites already available for new constructions (the “Venice Gateway for Science and Technology”).

Zone 2:

The gradual removal of petrol and crude oil deposits and production activities and realisation of a natural area with ecological values. In addition, an agreement for short-term improvements (“Petroven project”) of the area has been signed, which involves the main petrol companies: ESSO, AGIP and API. It includes the following provisions:

- The conjoint use and management of only one plant with high safety standard.
- The closing of the API deposits and part of the ESSO ones.
- The renovation of gas deposits and supply structures.
- 50% reduction of navigation within the lagoon, complete cessation of the navigation along the “Brentella” canal, substitution of present ships and oil tankers with higher safety standard ones.
- General improvement on technologies and the control devices.

Zone 3

Improvements to the railway network within this area, in particular along “Via della Eletticità”; removal of part of it in order to avoid any road crossing.

Zone 4

There is no particular provision for this area. However, the agreement stresses the importance of a further development of the commercial port activity, which involves

implementation of the railway network and of the port accessibility (the reader must remember that this area is, in fact, an island).

Zone 5

Improvements on its access from the south (Malcontenta) and from the north (“Via della Libertà» and “Via dell’Elettricità”), and of the railway network in general.

In addition, some industries have undertaken to perform the following relevant actions:

a) Enichem:

- substitution of the present plant for production of chlorine-soda,
- improvements to the deposits of phosgene and its derivatives (chlorine, ammonia, acrylonitrile),
- cessation of the production of the following dangerous substances: acetylene, ethylene acetate, vinyl monomer acetate, sodium cyanide and potassium, carbon oxide and hydrogen.
- Re-location of some activities to Ravenna.

b) Evc:

- A balanced production of CVM (vinyl chloride monomer) and PVC (polyvinyl chloride) in order to: reduce the rail, ships and oil tanker traffic, limit water usage, reduce micro pollution and air pollution in general.

c) Elf Atochem:

- General impact reduction and future de-location of its plants.

d) Ausimont:

- Reduction of the hydrochloric acid refuses and implementation of the production cycle.
- Control device improvements.

e) Montefibre :

- De-location of acrylonitrile plants.
- General safety improvements on plants.
- Reduction of polluted emission into the lagoon.
- Realisation of a new plant for producing acrylonitrile on site in order to reduce rail and maritime transportation of this hazardous substance.

f) Ambiente Spa:

- Adoption of new, more effective technology for biological treatment of waste substances.
- Capacity implementation of the plant for biological treatment of waste substances.
- Recycling of the water used for biological treatment of waste substances.
- Realisation of a new plant for biological treatment of contaminated mud and ground.

Zone 6:

Restoration and rehabilitation of the territory along the boundaries, realisation of a natural area between the industrial estate and the residential suburbs. Landscape and ecological rehabilitation of the “Naviglio Brenta” canal between Maclontenta and Fusina villages. In addition, some industries will undertake the following actions:

a) San Marco Petroli:

- General improvement to the environment and safety condition of its site.
- A study for de-locating its plants.

b) Sapió:

- Cessation of the acetylene bottling plant in order to eliminate the risk of major industrial accident.

c) Decal:

- Realisation of a new plant for toxic steam treatment.
- Renovation of the structure for railway and truck loading.
- Realisation of a new plant for acrylonitrile production.

6.2.2. The new Master Plan for Porto Marghera district.

The new Master Plan sets a zoning of Porto Marghera, in accordance with its main goal, which can be summarised as the economic rehabilitation of the area primarily by strengthening the existent commercial activities. This will also imply:

- improvements to rail and road network as well as the accessibility,
- implementation on the safety, restoration and re-qualification of the disused portions of the zone,
- realisation of some specific projects, in each zone.

In particular:

Zone 1

Here, the New Master Plan identifies the following spaces and functions:

- D1.2 – industrial area for maritime construction,
- D1.1 – industrial harbour completion area,
- D5 – new technological centre “Venice Gateway for Science and Technology” to be realised¹ in a degraded area along “Via della Libertà”.

This centre will include different functions, like a conference hall, a cultural centre (the ‘City of the Music’) and many technical and scientific laboratories. The area will be connected to the University of Venice, department of Mestre, which is located on the other side of the road, by a bridge. Besides the building demolition, land reclamation and urbanisation, an old

industrial edifice with particularly high archaeological value will be restored in order to be used as the conference hall.

Zone 2

the New Master Plan provisions for this area are:

- D/V – area dedicated to present petrol activities (deposits mainly), under the condition of a gradual cessation of these deposits, reclamation and transformation of the zone into a natural area.
- S/P – areas dedicated to general services like car parks, tourist offices, etc.

The zone shell is connected to the close regional park “San Giuliano”. This park is about 700 hectares wide, shared by Mestre Marghera and Campalto municipalities, and includes recreational as well as economic activities.

Zone 3

Zone 3 includes:

- part of the industrial harbour completion area - D1 1a
- D2 – area dedicated to commercial activities, reception services, offices and craftsmanship in general.

Despite the proximity of the Marghera suburb, residencies are not allowed, rather a further development of the present commercial activities only. In particular, the New Mater Plan will locate here – partially by restoring an old industrial edifice - a project named ‘The Craftsmanship Centre’. The construction of a new bridge over the Western Industrial canal also has to be mentioned which should improve the accessibility to Porto Marghera through “Via dell’Elettricità”.

Zone 4

This area includes the harbour only. Therefore, the New Master Plan zoning is:

¹ Indeed, the construction of part of it is already in progress.

- D1. 1a - industrial harbour completion area,
- D1. 3 - commercial harbour development area,
- F12 - existing commercial harbour area.

The provisions mainly focus on the main goal of the New Master Plan, i.e. expanding the commercial activities of the area. This project should involve also the exploitation of many under-used or completely disused sites. Deposits are no longer allowed in this zone, but infrastructure services and terminals only.

Zone 5

Here, the New Master Plan identifies the following spaces and functions:

- D1. 1a - industrial harbour completion area, again.
- D1. 1b - industrial harbour development area. It corresponds to the Second Industrial Zone, which is mainly occupied by large industries with their own piers.

However, this zone includes also a modest area (11 hectares) where small and medium enterprises can be located; therefore, this site will be subjected to reclamation and urbanisation.

Zone 6

It is divided into:

- D1. 1a industrial harbour completion areas, the ones already occupied,
- D1. 1b - industrial harbour development areas, the ones to be urbanised.
- D2 - one wide area dedicated to commercial activities, reception services, offices.

D2 is located near the town of Fusina, facing the lagoon, the eastern boundary of Porto Marghera. Here, a commercial and tourist terminal will be realised serving the historical centre of Venice: car parks, shopping centres, a camping site, a hotel, public and private dockyards. Two further areas are designed respectively for modest industrial activities (43 hectares) - which imply the construction of a new pier, too - and for small and medium

enterprises (21 hectares). Forecasts also involve improvements to the traffic network as well as the southern boundary. In the first case, accessibility to the area through the high way and the Malcontenta roundabout (the most important way into the estate) will be enlarged. In the second case, the territory along “Naviglio Brenta” canal will be reclaimed and turned into an ecological area.

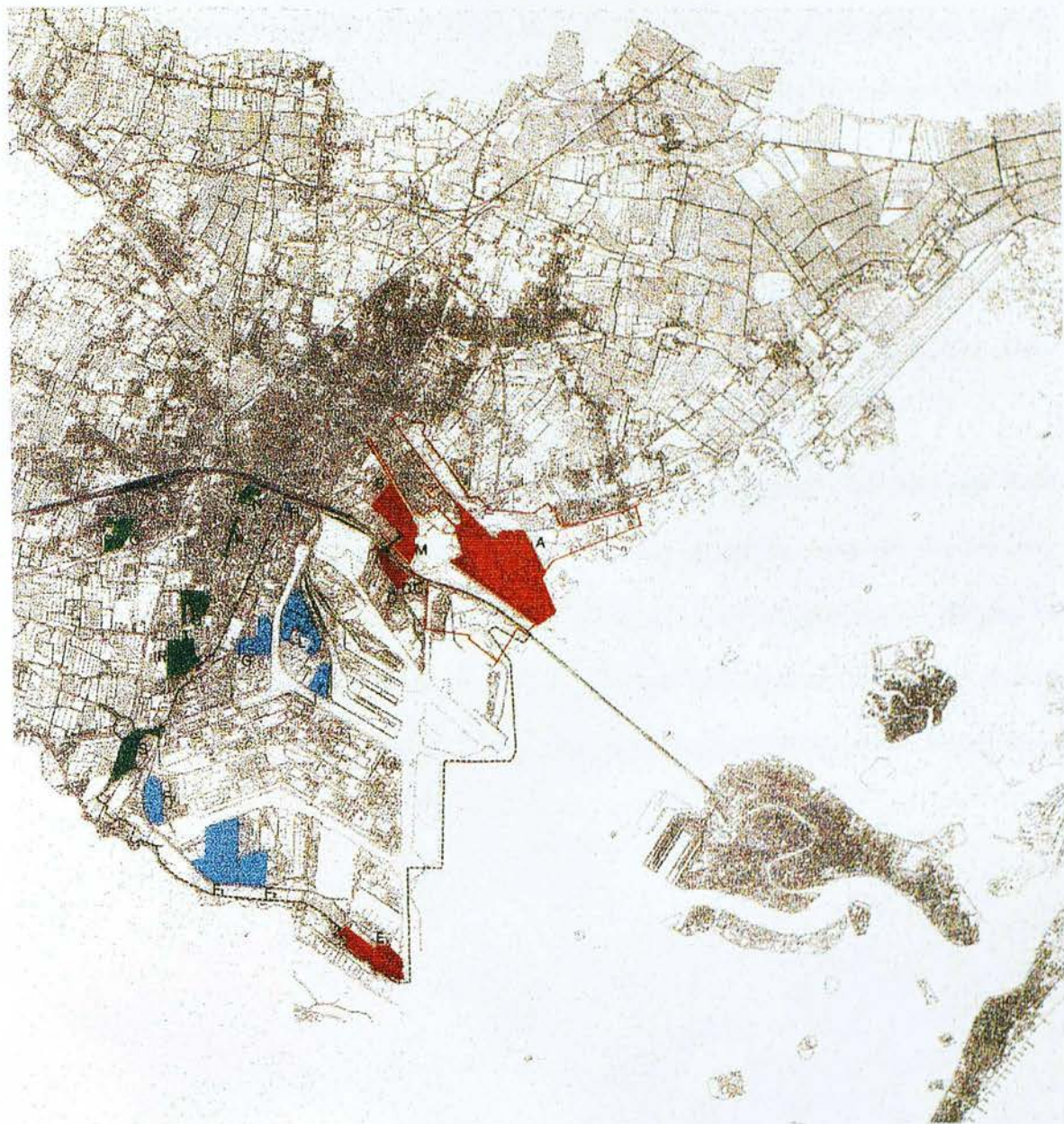


Figure 36: the most important areas included in the New Master Plan provisions (Comune di Venezia 1996).

6.2.3. The composite scenario

A description of this alternative is omitted since it results from the potential conjoint occurrence of the industrialists' mitigation actions and the New Master Plan outlook. In order to be more effective, the mitigation actions are supposed to take place before the Master Plan provisions. This circumstance is the most probable in terms of occurrence; however the two previous development programs have been conceived autonomously (and at different times); therefore, they can potentially occur independently as well². In particular, it must be noted that:

- The needs of a New Master Plan emerged many years ago; however, the approval and adoption of any urban program is always a controversial procedure, which depends on mainly political and economic interests. Therefore, the approval of the New Master Plan outlooks for Porto Marghera must not be taken for granted.
- The necessity of a short and long term industrial risk reduction program has been recently stressed by many different parties - environmentalists, residents, the Ministry of Environment – because of the disastrous conditions of the area. Again, despite its urgency, its adoption depends on political and economic interests. In addition, due to its voluntary character, it can be accepted by only a small percentage of industrialists.

² When the data was collected, the analysis performed, and this report written, the future of Porto Marghera was still unknown. However, now – about two years later – the composite scenario is already in progress.

Scenario	<i>The General Agreement on Chemical Hazard Mitigation Actions</i>	<i>The new Master Plan for Porto Marghera district</i>	<i>The composite scenario</i>
Statement	This is a long-term risk reduction program proposed by a general co-ordinating committee composed of the industrialists, the Minister of the Environment and the local authorities.	This is a local urban plan approved by the District Council. It sets a zoning of Porto Marghera, in accordance with its main goal in line with the most important Italian regulations on land use.	This results from the potential conjoint occurrence of the industrialists' mitigation actions and the New Master Plan outlook. This circumstance is the most probable in terms of occurrence.
Main goal	The rehabilitation of Porto Marghera and its transformation into an ecological industrial estate.	The economic rehabilitation of the area primarily by strengthening the existent commercial activities.	A general rehabilitation of the area pursued by further developing the commercial activities and reducing the risk of any industrial accidents.
General tasks	<ol style="list-style-type: none"> 1) Improvements in the railroad and maritime accessibility and internal transportation network. 2) General improvements in the plants safety measurements. 3) Dismantling and/or re-conversion of disused / partially in use plants, reclamation of the sites. 4) General measure for reducing air, water and land pollution. 5) Specific actions, undertaken by some industries, for reducing the risk of accident within their plants (adoption of more effective technologies, cessation or de-location of some hazardous activities). 	<ol style="list-style-type: none"> 1) Improvements of the present infrastructures (including tourist ones); 2) Introduction of cultural and educational activities. 3) Rehabilitation of green areas and realisation of a park. 4) Restoration and re-qualification of the disused portions of the zone. 5) Expansion of the commercial harbour 6) Realisation of some specific projects, in each zone, for expanding the commercial activities. 	<ol style="list-style-type: none"> 1) General improvements in the internal transportation network. 2) Dismantling / re-conversion of disused / partially in use plants, reclamation of the sites. 3) General improvements in the plants safety measurements. 4) Specific actions for reducing the risk of accidents (adoption of more effective technologies, cessation or de-location of some hazardous activities). 5) Improvements of the present infrastructures. 6) Introduction of cultural and educational activities. 7) Rehabilitation of green areas and the realisation of a park. 8) Expansion of the commercial harbour 9) Realisation of some specific projects for expanding the commercial activities in each zone. 10) General measures for reducing air, water and land pollution.

Table 11: a scheme of the three scenarios

6.3. *The experimental procedure*

The experimental assessment procedure is a framework model based on the multi-criteria analysis of expert opinions. It aims at assessing and controlling contributions to safety and security in industrial planning processes. Essentially, it is composed of two main parts: the first is a hierarchy of criteria, and the second is a table (matrix) of the choice options. The latter is a very common tool in Multi-criteria analysis, when studying impacts, and is a rough but practical manner for describing the choice options in terms of quantity and quality of their features. Subsequently, all these indicators are standardised and aggregated – following what has already explained in the ‘Environmental evaluation methods’ section – in order to obtain a priority rank of the objects of the study. In this case, the rank may describe the overall risk rate along with the efficacy of the development scenarios in terms of safety measures. As the main issue is very complex, the hierarchy is adopted in order to take all the possible objectives, sub-objectives and criteria, which may affect the choice option indicators, into account. In addition, it highlights and allows them to be judged as well as their relationships by using weights, which are taken into account in the rank computation. The hierarchy considers qualitative criteria, while the matrix regards quantitative (or semi quantitative) features. Theoretically, however, it could also include qualitative elements. The hierarchy is based on the reasoning below. Porto Marghera is divided into different zones of more or less homogeneous land use. Therefore, the total risk of Porto Marghera results from the aggregation of risks of each zone. This local risk refers to the possible consequences of any industrial accident: hospitalisation (injuries) and fatalities. The proportion of injuries to deaths (or vice versa) varies according to zones, while the magnitude of these consequences depends on the people present in the area at the moment of the accident (residents, workers, etc.) and the type of accident (explosion, gas emission, etc.).

Each accident can be generated by different factories and transportation means. At the bottom of the hierarchy there are the choice options that will be assessed according to the number of future plants/transportation means and of the people they will locate in each zone.

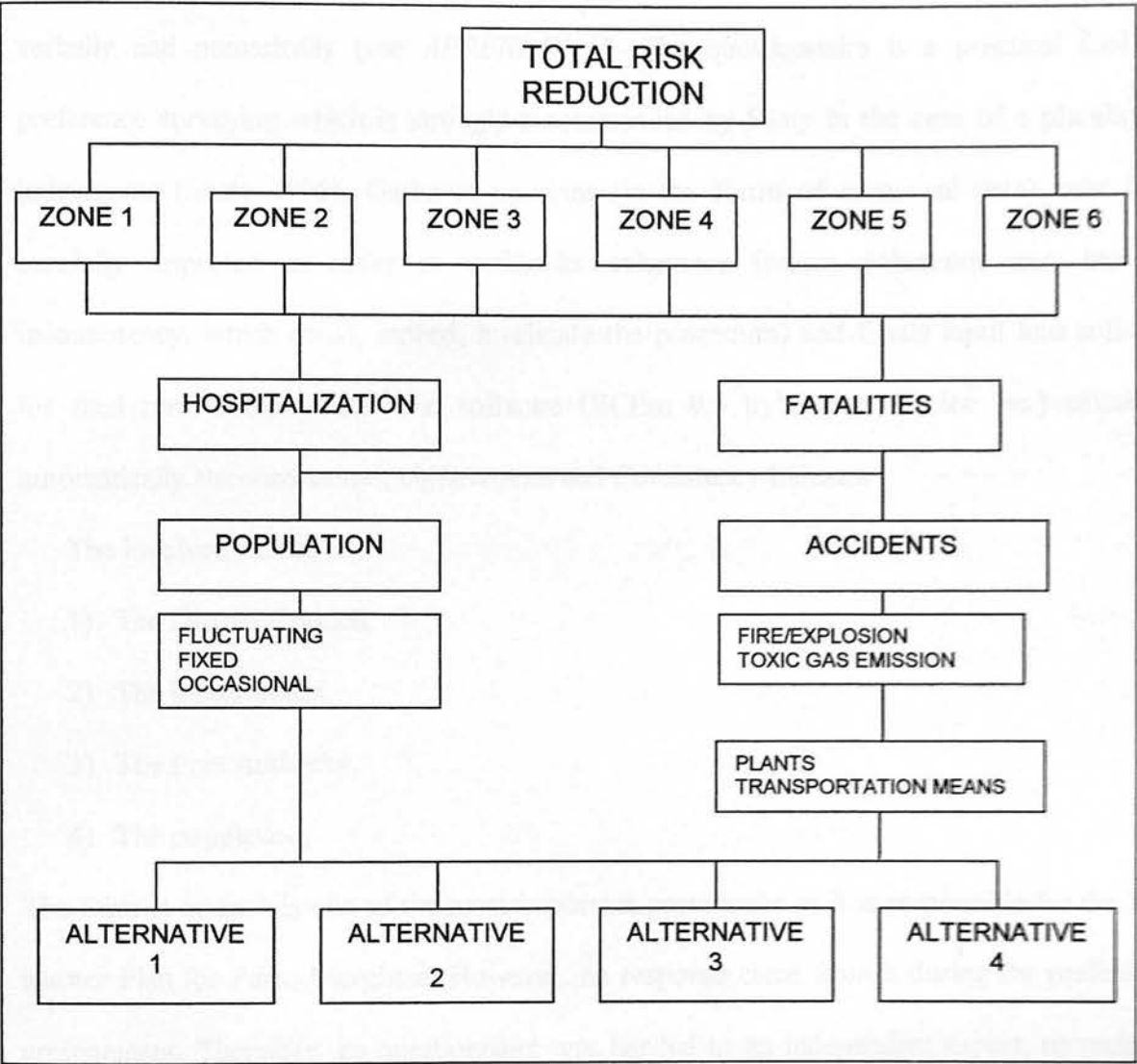


Figure 37: the hierarchy

6.4. Gathering judgements

In line with the AHP procedure, after building the hierarchy, the relative importance of the criteria and that of the scenarios have been determined on the basis of the decision

maker/s' preferences and/or opinions. Judgements were gathered from the involved parties by using a precise procedure. First, involved people and respective objectives and sub-objectives have been identified. Following this, representatives have been chosen among them (one for each category – with the exception of the inhabitants), and have been asked to fill in a questionnaire, where individual preferences or judgements can be expressed both verbally and numerically (see *APPENDIX F*). The questionnaire is a practical tool for preference surveying which is strongly recommended by Saaty in the case of a plurality of judgements (Saaty 1995). Gathered opinions (in the forms of numerical data) have been carefully inspected in order to verify its coherence (scarce coherence may increase inconsistency, which could, indeed, invalidate the procedure) and finally input into software for final rank computation. The software (ECPro 9.5 by Expert Choice inc.) calculates automatically standard values, eigenvectors and Consistency Indexes.

The involved parties are:

- 1) The District Council,
- 2) The industrialists,
- 3) The Port Authority,
- 4) The population.

The District council is one of the most important protagonist as it is responsible for the New Master Plan for Porto Marghera. However, no response came from it during the preliminary arrangement. Therefore, its questionnaire was handed to an independent expert, an architect who had carefully studied the Porto Marghera situation in general and the New Master Plan in detail. The industrialists front is a very homogeneous party not only because of common interests, but also because of strong relationships and dependence among the companies in terms of production sequence and sometimes dependence to the same shareholders. The industrialists are profoundly involved in the proposal for the 'General Agreement on Chemical

Hazard Mitigation Actions'. The questionnaire was handed to the Director General of the Porto Marghera Industrialists' Association. The Venice Port Authority did not propose any development scenario; however, its opinion is fundamental as the authority is responsible for the safety of the harbor area and is the main party to have commissioned the official Safety Report. In fact, the questionnaire was handed to the Director of the Safety and Environment Department of the Venice Port Authority.

Population may be distinguished into:

- 1) Mestre and Marghera residents, who may be affected by any Major Hazard Accident,
- 2) Workers of Porto Marghera industries,
- 3) Tourists and other occasional visitors to the Porto Marghera estate.

They were, however, considered as important criteria assessed by the experts. Due to this, population was not directly questioned in order to avoid invalidating the procedure (i.e. for them not to give an opinion on themselves). Nevertheless, in 1988, the ARPAV Authority conducted a survey titled 'Report on Risk Information Survey Concerning Marghera Residents', which provided useful information on the people's perception of risk in Porto Marghera and on the most frequent incident typologies. The ARPAV experts suggested taking this data into consideration in this analysis. Due to its incompleteness, part of this data was utilised only for integrating that from the questionnaires and utilised for sensitivity analyses.

The questionnaire is modelled on the base of the hierarchy. It is divided into three parts: the first is generic and asks the contribution of each zone to the global risk; the second is specific for every zone and concerns the factors affecting the local risk:

- type of risks (fatality versus injury),
- type of accidents (toxic gas release versus fire/explosion),
- type of accident sources (plant versus transportation mean),

- type of present population (residents / workers / tourists).

In the last part, every choice option is assessed on the basis of these factors and with respect to the main goal. The questions are presented in the form of pair wise comparison; therefore, the respondent is asked to assess the relative dominance of each criterion relative to the others. The last part - the matrix - is assessed by using a rating technique in order to reduce its length and make the computation of the final rank easier.

The complete document resulted in 87 questions and 8 matrices to be compiled.

7.1. Preface to results

The procedure has been split into seven different parts - one for each zone - and a control hierarchy to aggregate the zone priorities. The latter is used to compare the components of the system, while the others are used to compare the elements. The final scores have been computed by applying the principle of hierarchy composition; that is to say, the weights of the parent criteria multiply those of the sub criteria. Subsequently, the overall priorities are obtained by summing the results of this operation (additive model). The consistency index of the hierarchy is obtained by summing the products of the consistency index of each matrix and the appropriate priority. This procedure is approximate in the sense that the additive model should be applied in case of independent criteria only, while part of our hierarchy presents interdependence due to the complexity of the problem.

7.2. The outcomes

Seven sets of results are presented:

- 1) Independent expert's results,
- 2) The Director General of the Porto Marghera Industrialists' Association assessment,
- 3) The Port Authority of Venice assessment
- 4) Results from integrated data assessment no. 1 (population survey data and expert's data)
- 5) Results from integrated data assessment no. 2 (population survey data and Director's data)

- 6) Results from integrated data assessment no. 3 (population survey data and Port Authority's data)
- 7) A composite set of priorities derived from the geometric means of the players' judgements.

The model automatically calculates global and local priorities for each set of data. However, local priorities are also interesting as they represent the contribution of each zone (and that of each scenario in every zone) to the global risk rate. Sometimes, the inconsistency ratio is higher than 0.1. In this case, sensitivity analyses are performed on the inconsistent judgements.

7.2.1. The independent expert assessment

Globally, the General Agreement on Chemical Hazard Mitigation Actions is assessed as the most efficient. However, the inconsistency index corresponding to the first part of the questionnaire is quite high; therefore, new judgements have been introduced automatically and a new set of priorities has been calculated. New results do not differ from the original ones. The local assessment results are:

- Zone 1 best-ranked alt.: the Mitigation Actions.
- Zone 2 best ranked alt.: the composite scenario.
- Zone 3 best ranked alt.: the composite scenario.
- Zone 4 best ranked alt.: the Mitigation Actions.
- Zone 5 best ranked alt.: the Mitigation Actions, followed by the composite scenario.
- Zone 6 best ranked alt.: the Mitigation Actions, followed by the composite scenario.

The sensitivity analysis on the external expert's weights highlights that the rank of zone 1 and 3 are affected by the population criteria (in particular, fluctuating population).

total risk reduction - expert's assessment

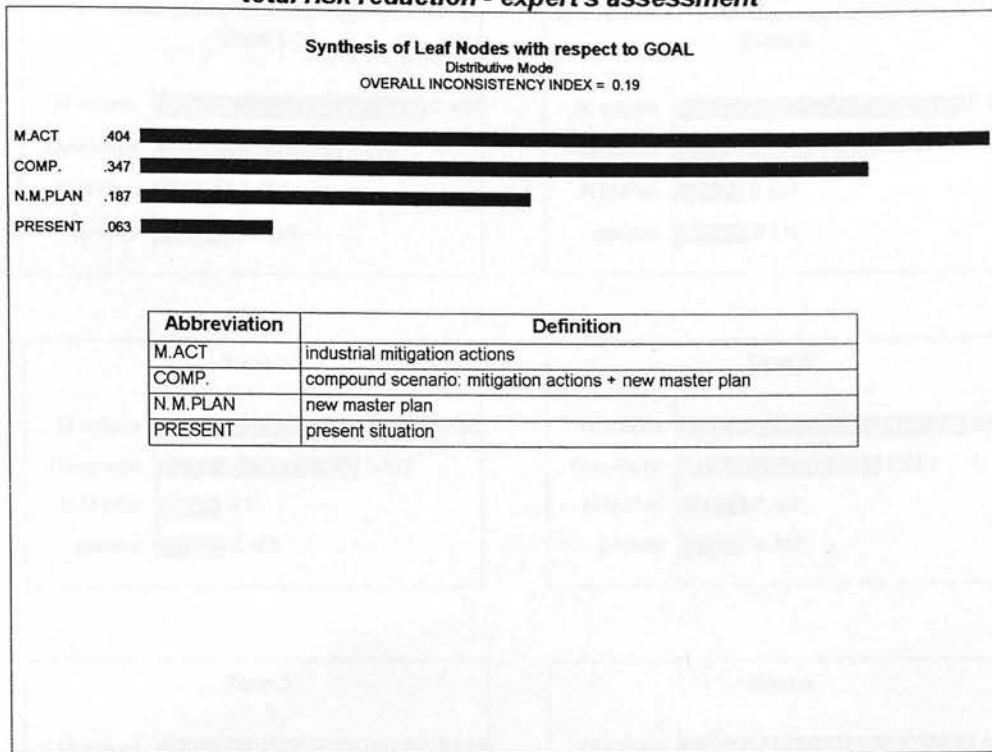


Figure 38: external expert's assessment – global scores

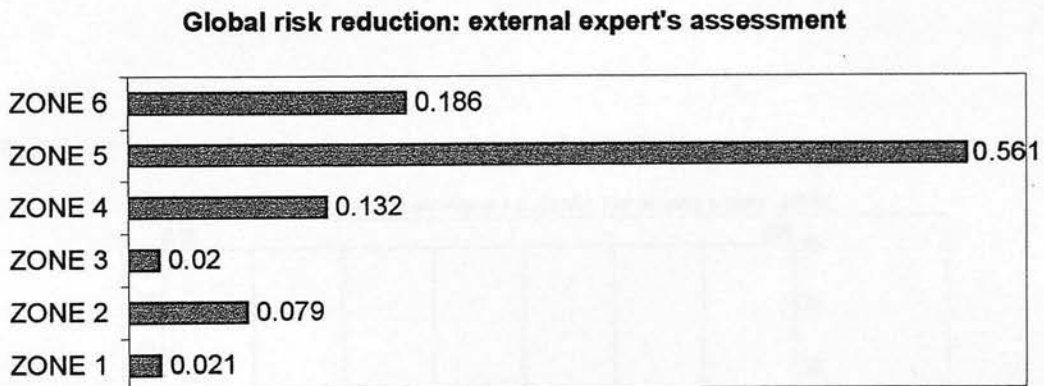


Figure 39: external expert's assessment – zones priorities.

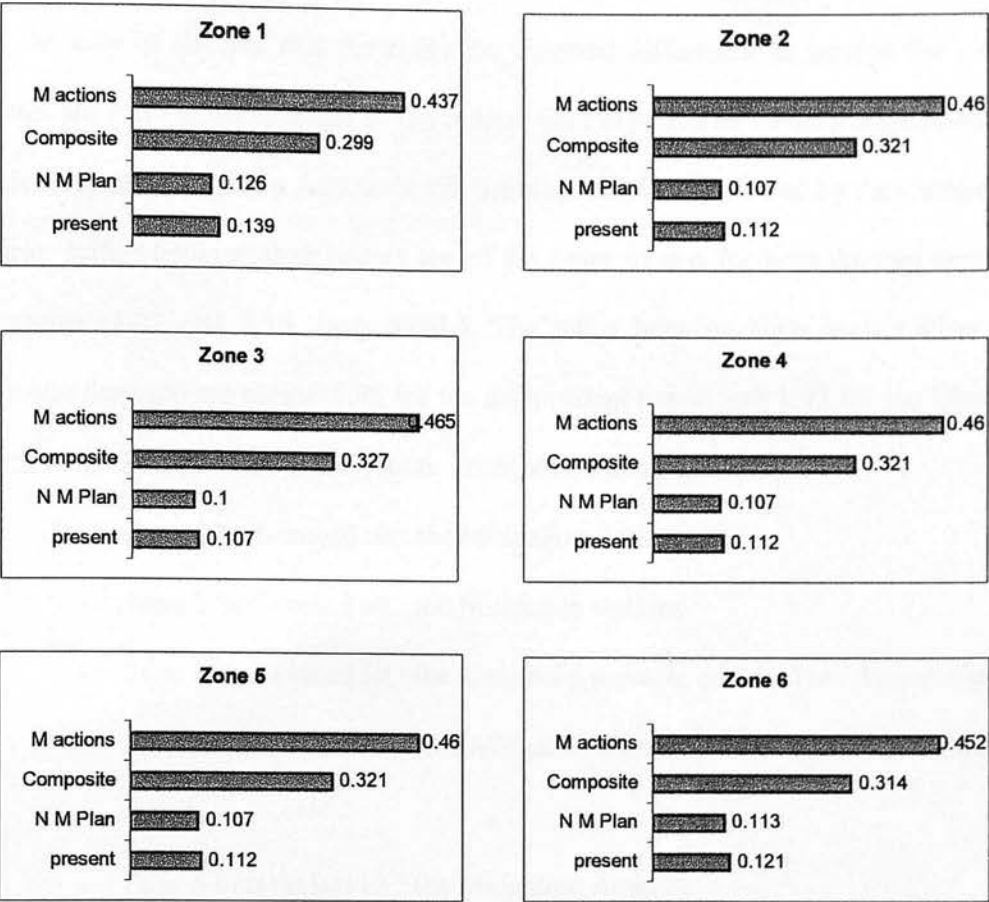
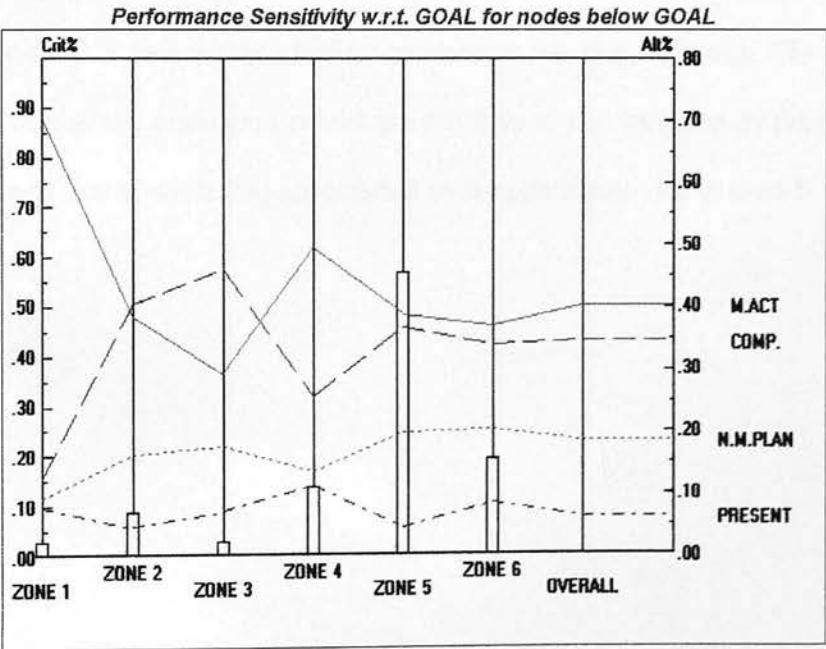


Figure 40: external expert's assessment – local priorities



In spite of the fact that the zones are assessed differently, in general the global priorities are still similar to those of the independent expert. The General Agreement on Chemical Hazard Mitigation Actions is still the most efficient, followed by the Composite Scenario. Ratios between their scores are of the order of one for both the two experts' assessments (1.02 and 1.16, respectively). The ratios between New Master Plan and Composite Scenario are closer: 1.85 for the independent expert and 1.92 for the Director General of the Industrialists' Association. Local assessments are:

- Zone 1 best-ranked alt.: the Mitigation Actions.
- Zone 2 best ranked alt.: the Mitigation Actions.
- Zone 3 best ranked alt.: the composite scenario and the New Master Plan.
- Zone 4 best ranked alt.: the Mitigation Actions followed by the composite scenario.
- Zone 5 best ranked alt.: the Mitigation Actions.
- Zone 6 best ranked alt.: the composite scenario and the Mitigation Actions.

Major variations are in the local evaluation of zone 2 (oil tank and refinery), zone 3 (office area) and zone 4 (the commercial harbour). There, the New Master Plan has been evaluated as a reasonably efficient instrument for risk reducing. The sensitivity analysis shows that the evaluation results are sensitive to any variation of the population weight in zone 1 and 6, while they are affected by hospitalisation risk in zone 5.

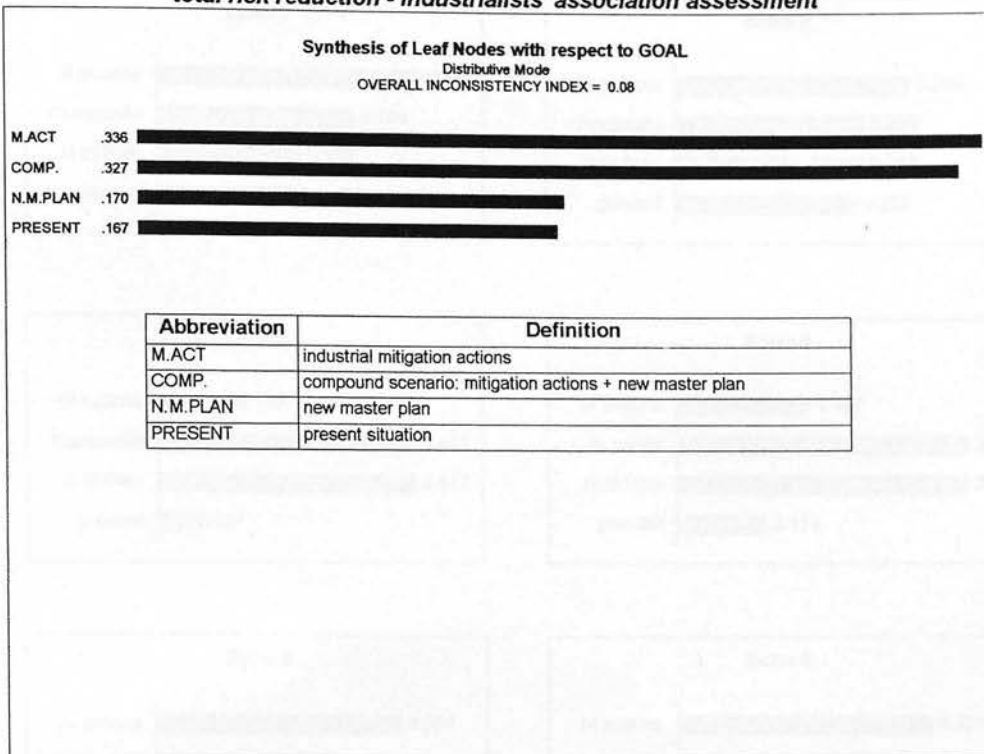


Figure 42: General Director– global scores.

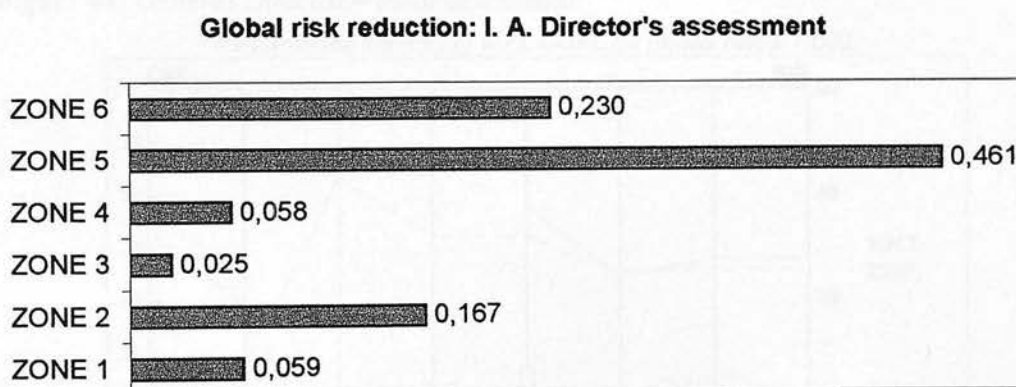


Figure 43: General Director – zones priorities

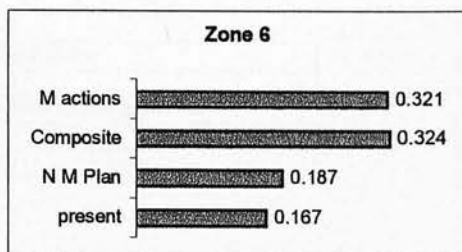
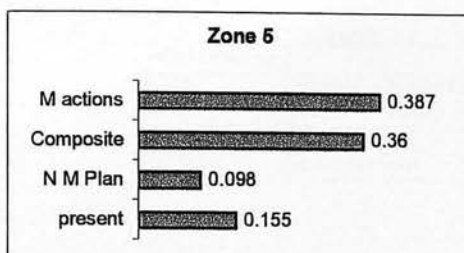
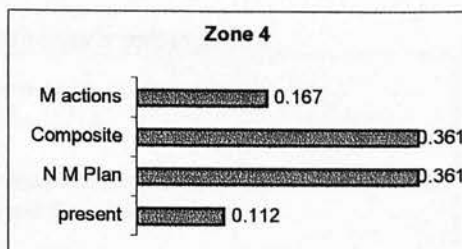
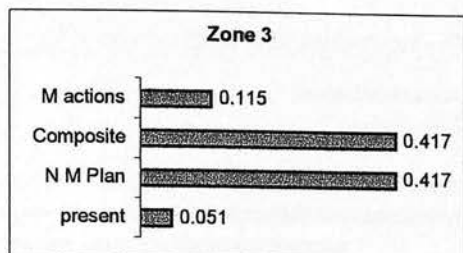
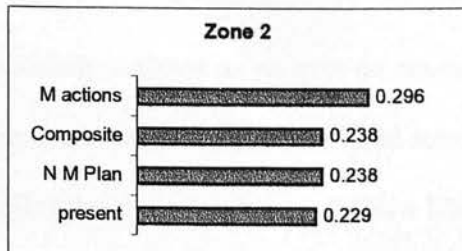
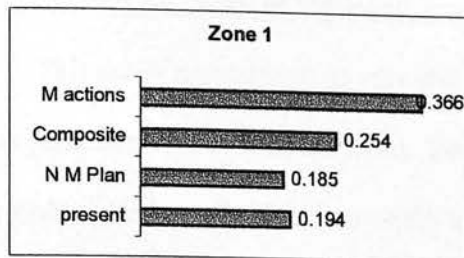


Figure 44: General Director – local assessment

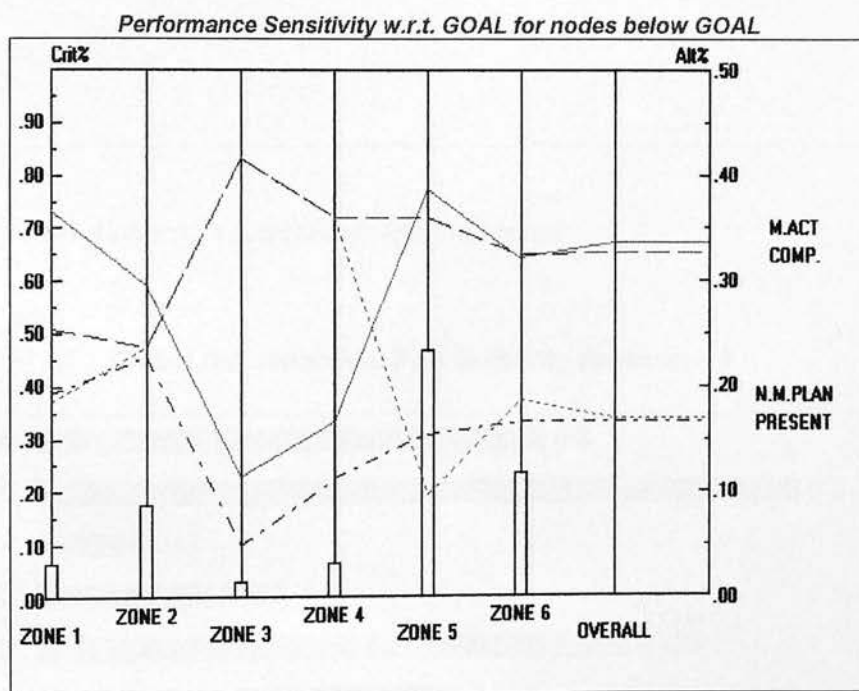


Figure 45: General Director – sensitivity analysis

7.2.3. The Port Authority of Venice assessment

This set of assessments is very stable: sensitivity analyses on weights do not result in any particular variation of the ranks. The Mitigation Actions is the best-ranked scenario both globally and locally. It is interesting to note that the choice option no. 3 (New Master Plan) is evaluated as the least useful.

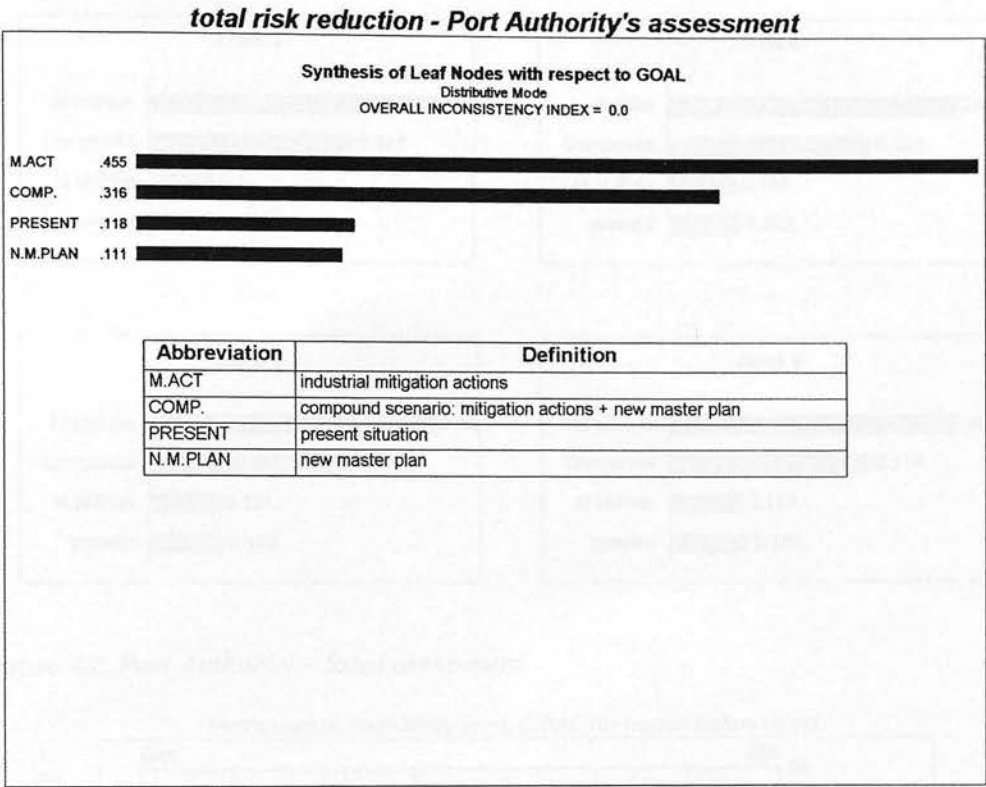


Figure 46: Port Authority's assessment – global scores.

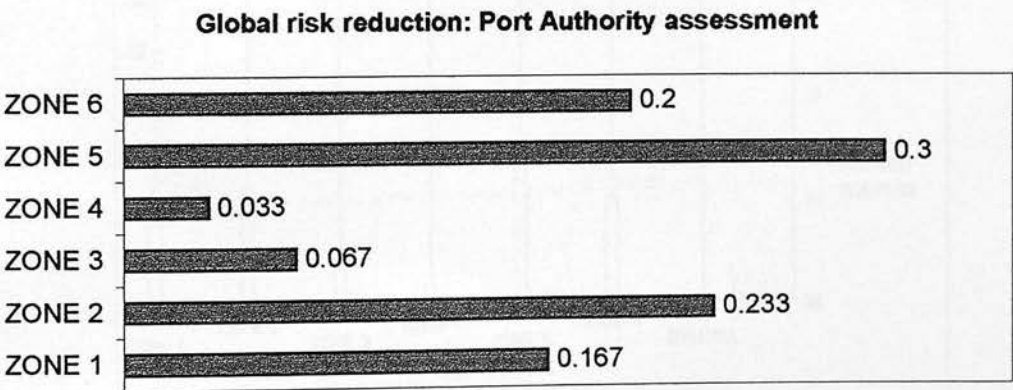


Figure 47: Port Authority's assessment – zones priorities.

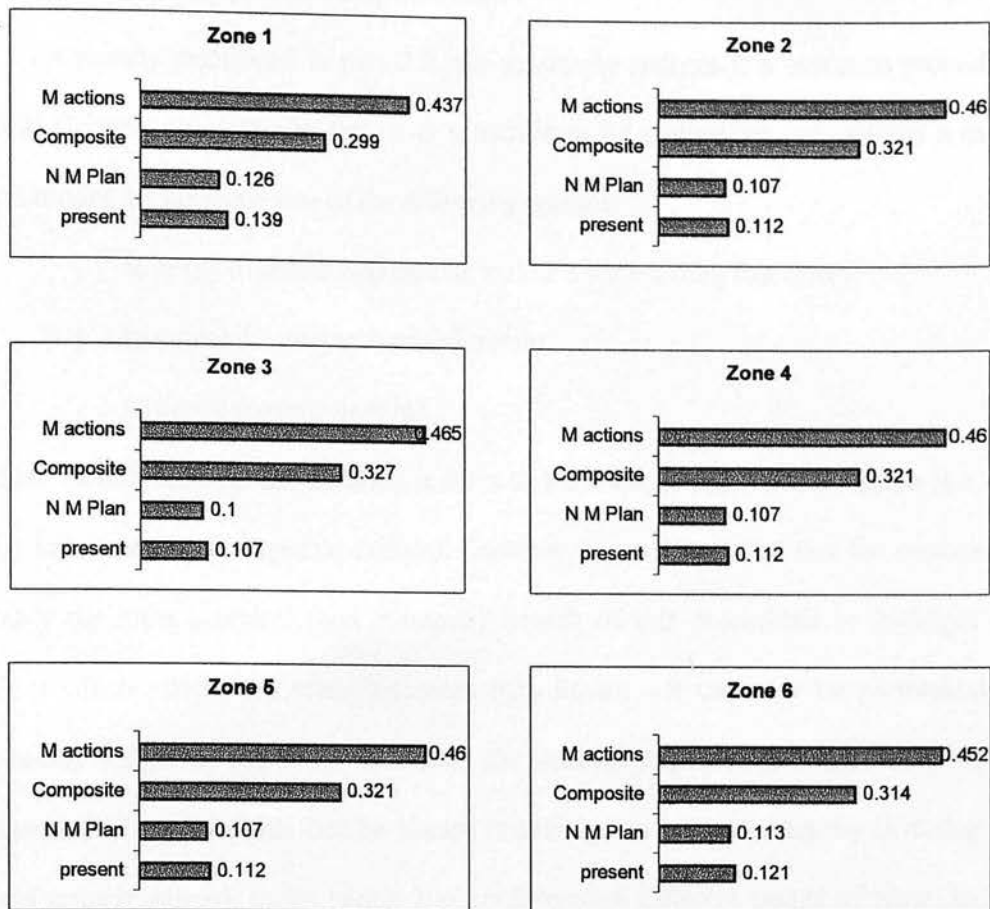


Figure 48: Port Authority – local assessment

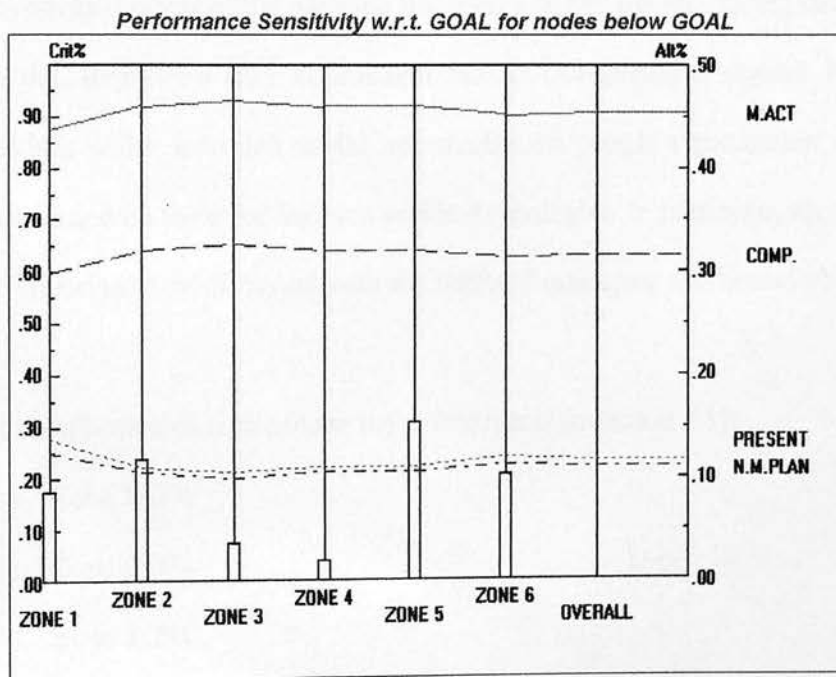


Figure 49: Port Authority – sensitivity analysis

7.3. The sensitivity analysis on integrated data

As already mentioned in par. 3.2, the sensitivity analysis is a common procedure in Multi Criteria Analysis. In fact, it is a technique for testing the outcome of a multi criteria model, by pursuing one of the following options:

- to apply different aggregating and/or standardising functions,
- to assess the alternatives differently,
- to introduce new weights.

All these techniques help the decision makers to look for the most stable option (i.e. not greatly influenced by changeable factors). However, it must be noted that the opposite is probably the most practical (and common) benefit of this procedure: to highlight the criterion which affects the scenarios more than others. It can only be performed by introducing weight assignments other than the decision maker's ones and verifying the outcomes. Different weights can be chosen randomly, on purpose (e.g. by inverting the original criteria values), or by taking into consideration different points of view. In line with these reasoning and the ARPAV experts' suggestion (see *APPENDIX L* and par. 6.4), the sensitivity analysis of the outcome has been pursued by introducing new weights taken from the 'Report on Risk Information Survey Concerning Marghera Residents' (ARPAV 1988), which provided useful information on people's perception of risk in Porto Marghera and on the most frequent accident typologies. In particular, the following is the most important data discussed with the ARPAV managers and considered into the procedure:

- 1) The contribution of each zone to the global risk is (question 3.1):
 - a. Zone 1: 2%
 - b. Zone 2: 4%
 - c. Zone 3: 2%
 - d. Zone 4: 0%

e. Zone 5: 62%

f. Zone 6: 30%

- 2) Accepting the fact that the residents do not accept moving away because of any industrial risk (ARPAV 1997, 'Risk Information Survey Concerning Marghera Residents', internal paper), the relative 'dominance' of variation in accidents on that in population, compared to risk reduction, is at a maximum (9).
- 3) The priority of toxic substance emission toward fire and/or explosion is 3. In fact, the ARPAV questionnaire included other five risks of accident. Therefore the percentages are: toxic substance emission 33.1%, fire and/or explosion 10.4%. This data has been entered both directly and as relative percentage.
- 4) Question no. 2 of the ARPAV survey shows that residents judge the contribution of transportation means and plants to the accident risk reduction equally.

These weights have been introduced into the three experts' assessments obtaining the outcomes plotted in the following charts. The weight sensitivity analyses have been performed for highlighting the most significant criteria, which affect the major industrial hazards in Porto Marghera. Due to the incompleteness of the input data, this assessment must only be considered as additional information. Therefore, the most remarkable considerations are:

- 1) Zone rank and toxic hazard are the most critical factors (in local assessments).
- 2) The global ranks of each player are not affected by the introduction of new data.
- 3) The Mitigation Actions is still the best-ranked scenario.
- 4) The local ranks from the Port Authority's evaluation are not sensitive to this analysis.
- 5) In contrast, the Industrialists' local assessments are completely altered.

total risk reduction: integrated data assessment no. 1

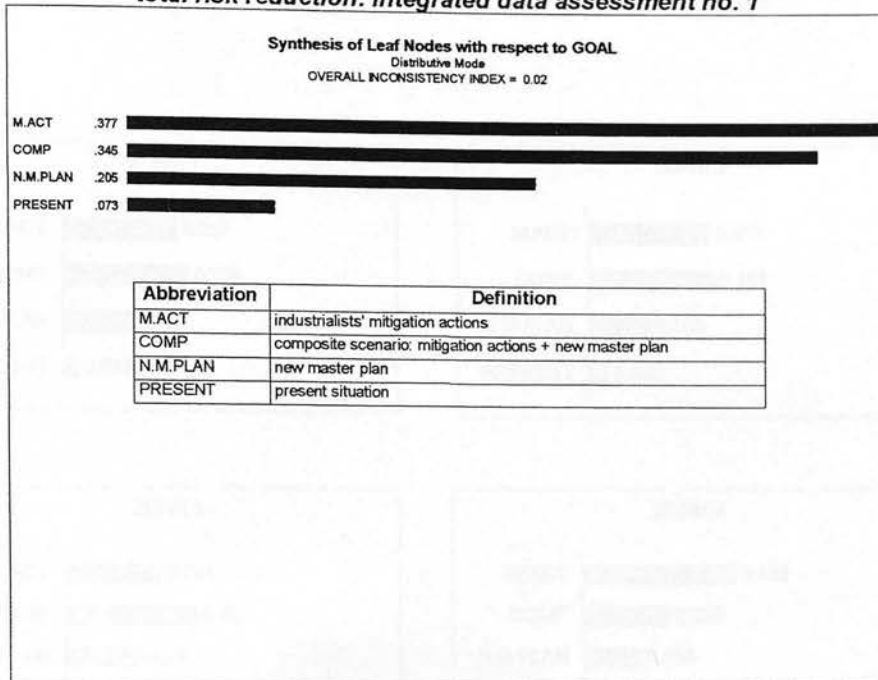


Figure 50: sensitivity analysis - global scores (ARPAV survey and external expert's opinions)

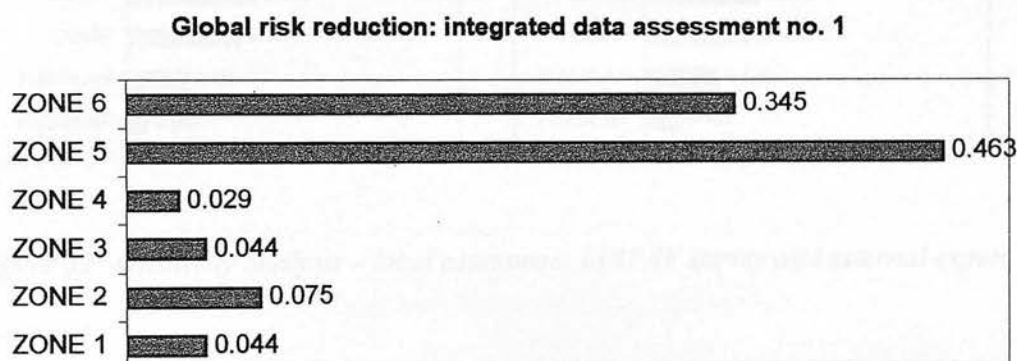


Figure 51: sensitivity analysis – zones priorities (ARPAV survey and external expert's opinions)

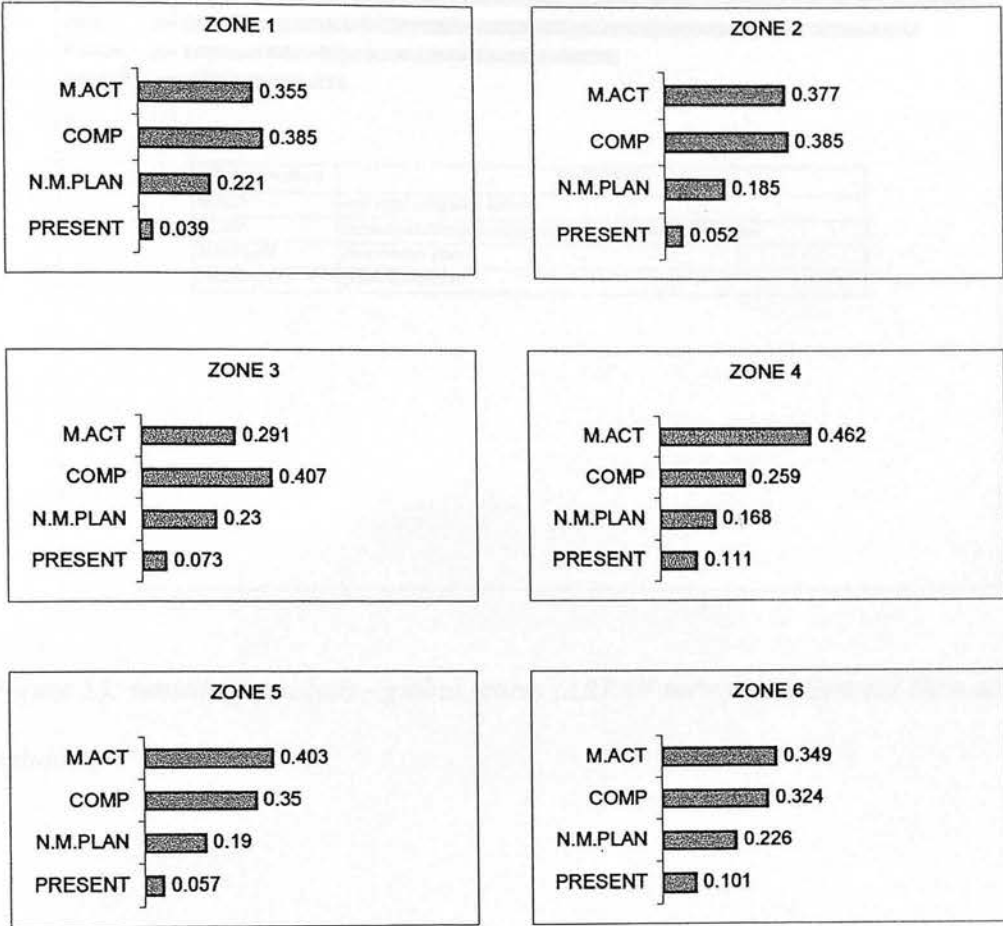


Figure 52: sensitivity analysis – local assessment (ARPAV survey and external expert's opinions)

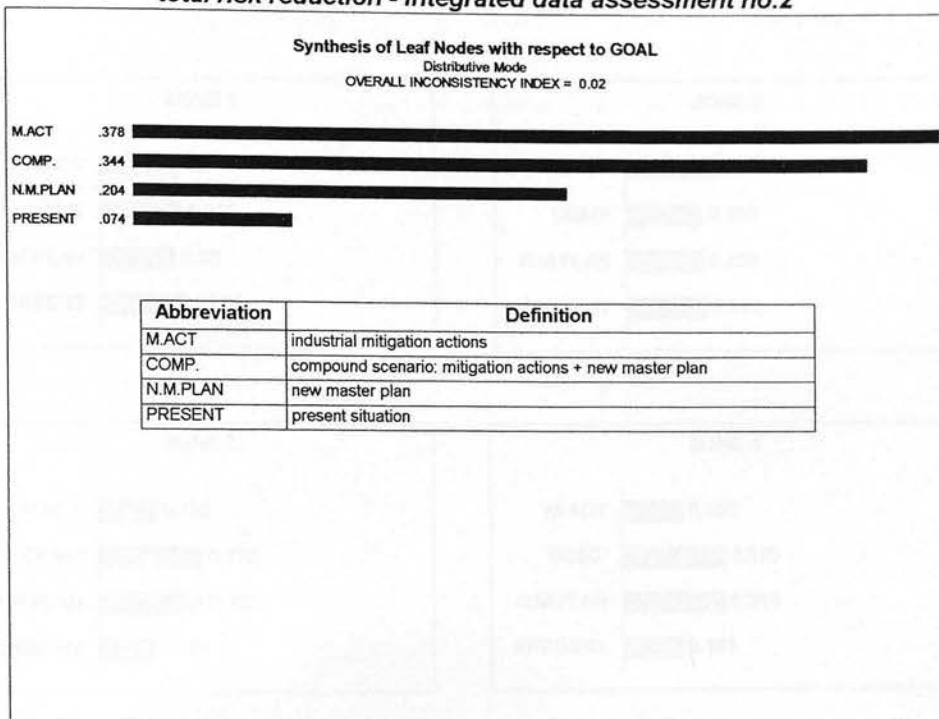


Figure 53: sensitivity analysis - global scores (ARPAV survey and General Director's opinions)

Global risk reduction: integrated data assessment no. 2

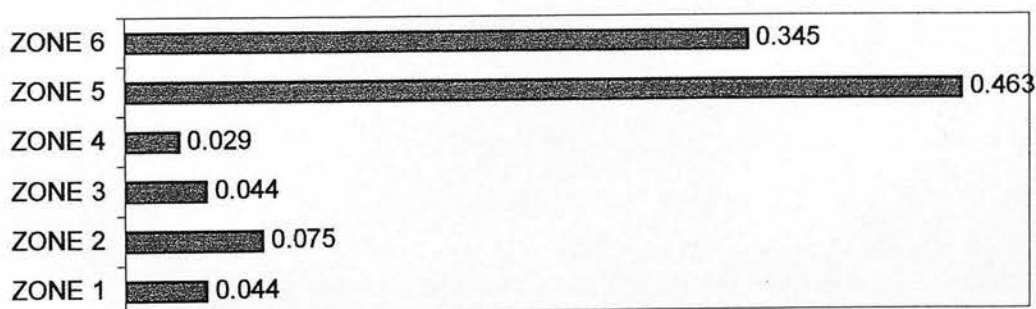


Figure 54: sensitivity analysis— zones priorities (ARPAV survey and General Director's opinions)

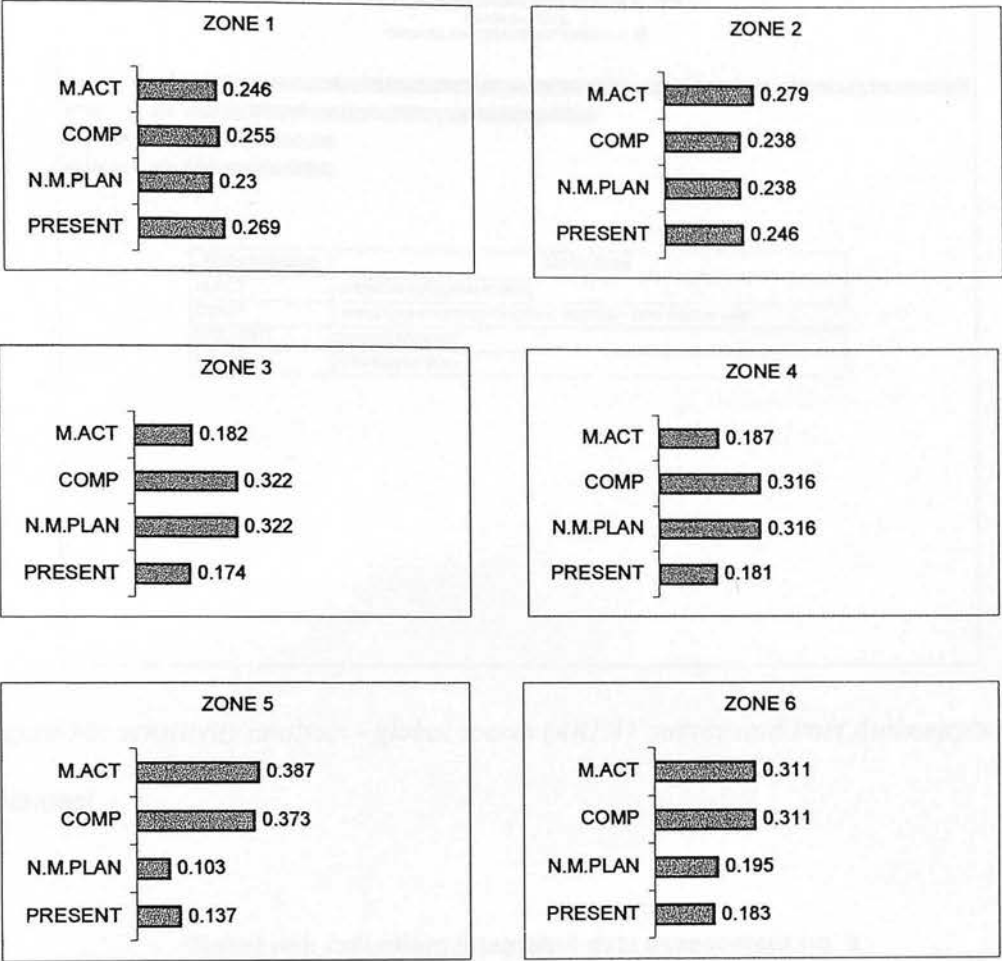


Figure 55: sensitivity analysis – local assessment (ARPAV survey and General Director’s opinions)

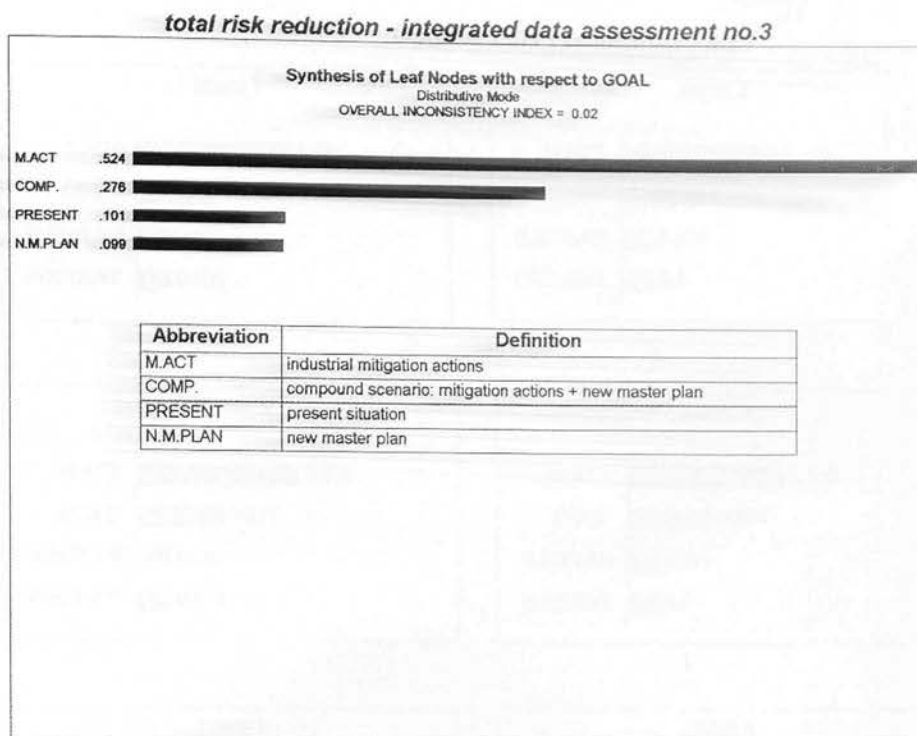


Figure 56: sensitivity analysis - global scores (ARPAV survey and Port Authority's opinions)

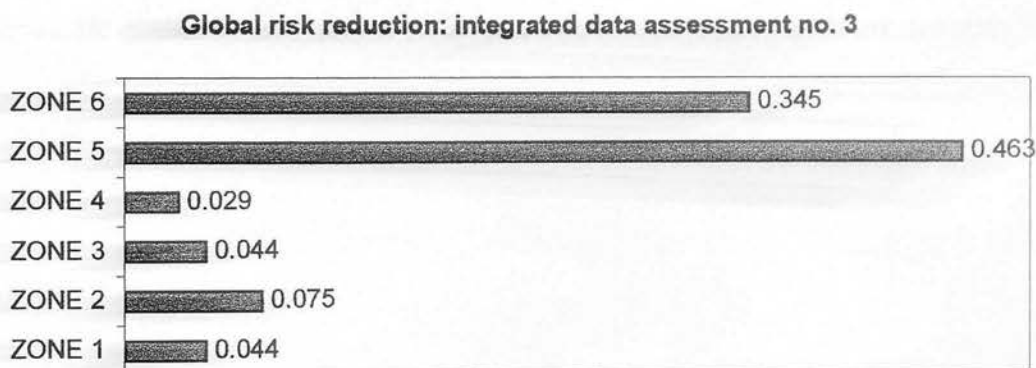


Figure 57: sensitivity analysis- zones priorities (ARPAV survey and Port Authority's opinions)

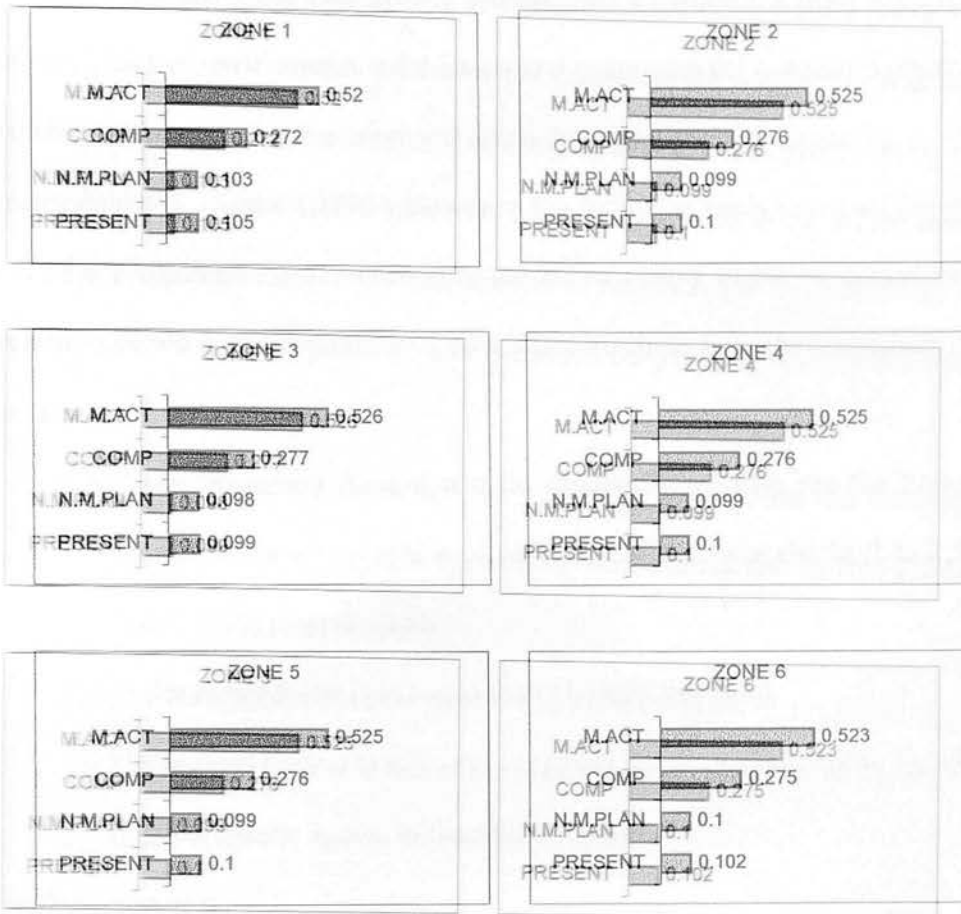


Figure 58: sensitivity analysis - local assessment (ARPAV survey and Port Authority's opinions)

There are many ways of getting a unique set of priorities from a plurality of judgements. The geometric mean is the fastest and guarantees the conditions under which the results can be accepted: the axioms of symmetry, agreement, homogeneity, reciprocity and separability (T. L. Saaty, 1996). However, this technique tends to cut off the extreme values of the considered data. Therefore, the set of results might be considered as a compromise between different points of view. Main outcome from the assessment are:

- Globally:

- a) The Mitigation Actions and the composite scenario are the best-ranked options. They are capable of reducing the industrial risk by 2 to 2.5 times that of the present situation.
- b) The New Master Plan seems to not be effective at all.
- c) The most risky area is that of the petrol chemical plants (zone 5), while the safest is zone 3, next to the residential area.

- Locally (figure 61):

- a) The Mitigation Actions is a valid instrument in zone 5 and 2, where the risk level might decrease by 2.8 and 1.9 times that of the present situation, respectively.
- b) In zone 3, the composite scenario reduces the risk level 3.2 times that of the present situation.
- c) All the alternatives are very efficient in zone 1 (more than 10 times).

total risk reduction - geometric means

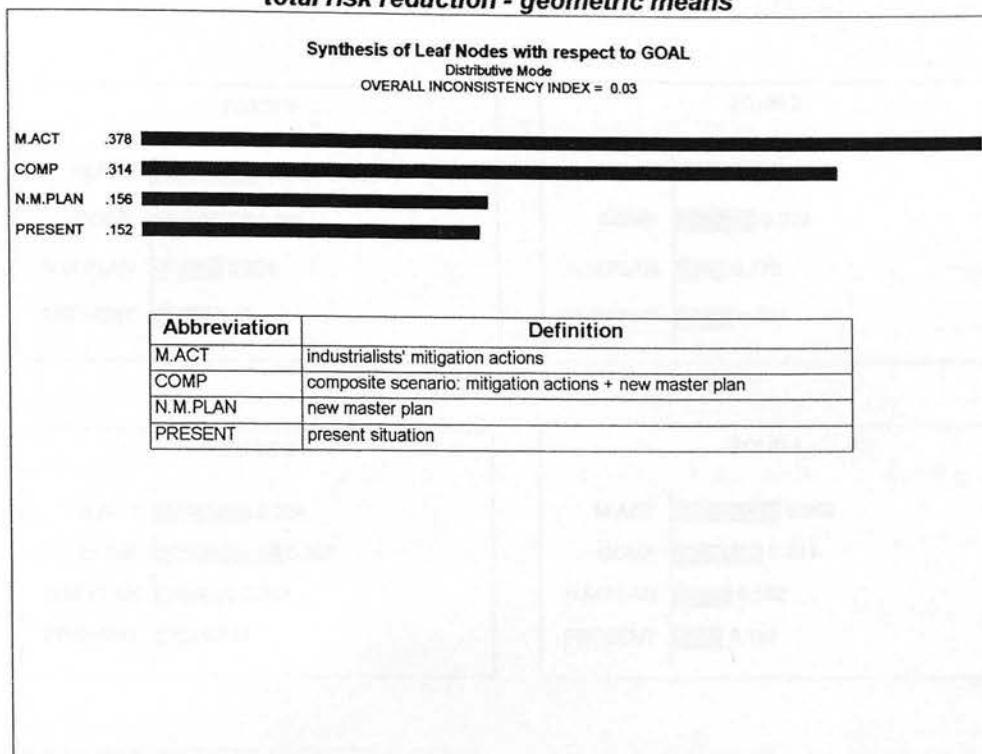


Figure 59: global priorities on aggregated data.

Global risk reduction: geometric means

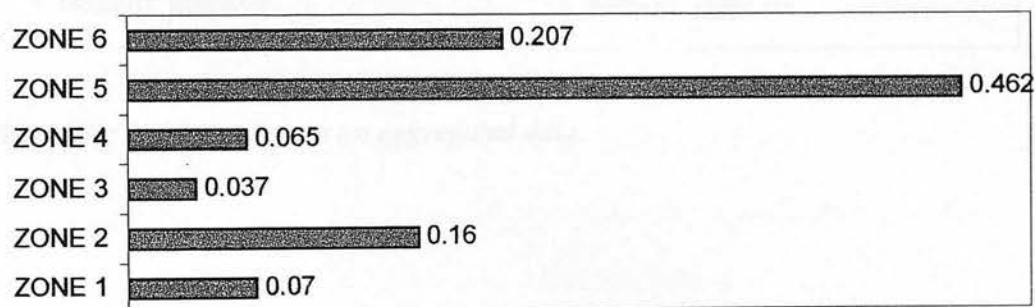


Figure 60: aggregated data – zones priorities

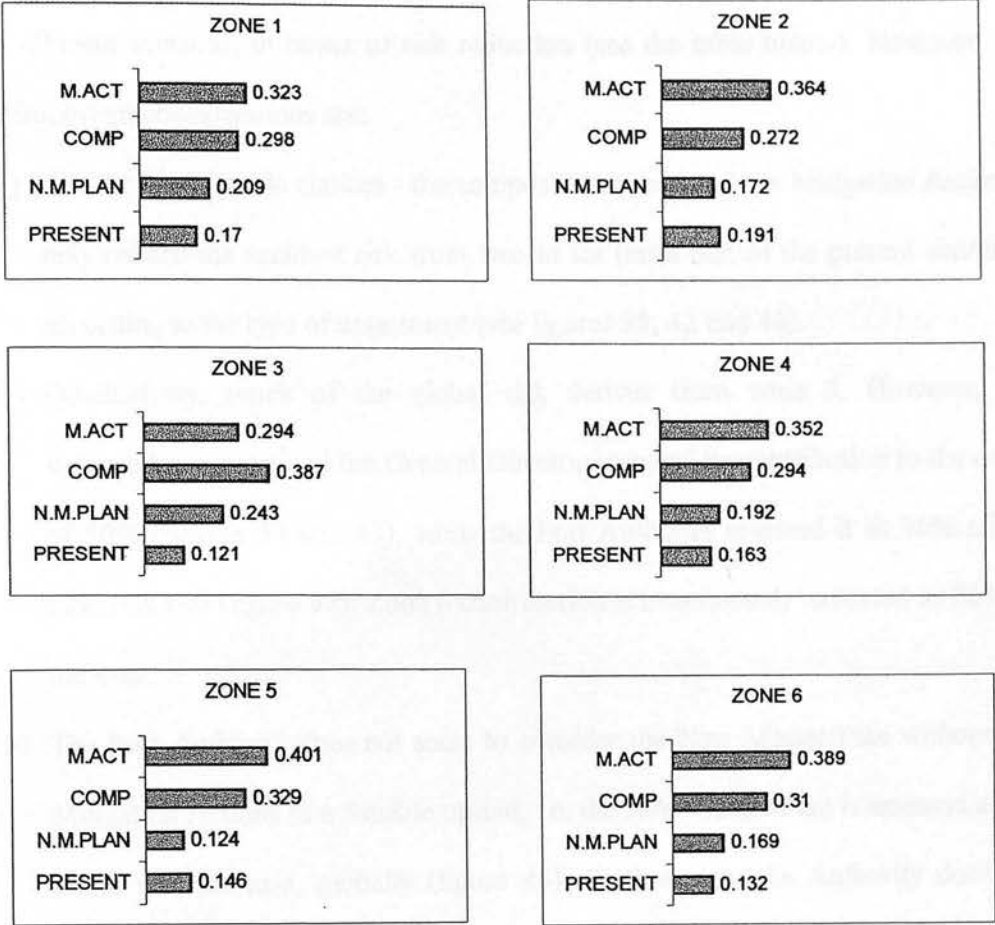


Figure 61: local assessment on aggregated data.

7.5. Notes on results and recommendation concerning the first section

Generally speaking, it can be said that, qualitatively, the three experts agree on the most efficient scenario, in terms of risk reduction (see the table below). However, the most important considerations are:

- 1) The most preferable choices - the composite scenario and the Mitigation Actions - may reduce the accident risk from two to six times that of the present situation, according to the type of assessment (see figures 38, 42 and 46).
- 2) Qualitatively, much of the global risk derives from zone 5. However, the independent expert and the General Director assessed its contribution to the order of 50% (figures 39 and 43), while the Port Authority assessed it as 30% of the total risk rate (figure 47). Zone 6 contribution is unanimously indicated as 20% of the total.
- 3) The Port Authority does not seem to consider the New Master Plan without any Mitigation Actions as a feasible option, i.e. the New Master Plan is assessed as the worst risk scenario, globally (figure 46). Furthermore, the Authority does not consider the risk of the commercial harbour area as significant (figure 47).
- 4) On the basis of the criteria priorities and of the sensitivity analyses on weights (figures 41, 45 and 49), the population factor, the hospitalisation risk and that of toxic substance release appear to be the most critical factors.

General resume charts are presented at the end of this section.

	External Expert	Director General	Port Authority
Zone 1	Mitigation actions	Mitigation actions	Mitigation actions
Zone 2	Composite scenario	Mitigation actions	Mitigation actions
Zone 3	Composite scenario	Composite scenario	Mitigation actions
Zone 4	Mitigation actions	Mitigation actions	Mitigation actions
Zone 5	Mitigation actions	Mitigation actions	Mitigation actions
Zone 6	Mitigation actions	Mitigation actions and composite scenario	Mitigation actions
Global	Mitigation actions	Mitigation actions	Mitigation actions

Table 12: best ranked scenarios.

It is not possible to make any consideration on the residents' assessment, due to the incompleteness of the input data. However, the population seems to understand the risk of any industrial accident in zone 5 (see sensitivity analysis charts). Therefore, it is recommended to further investigate in this direction.

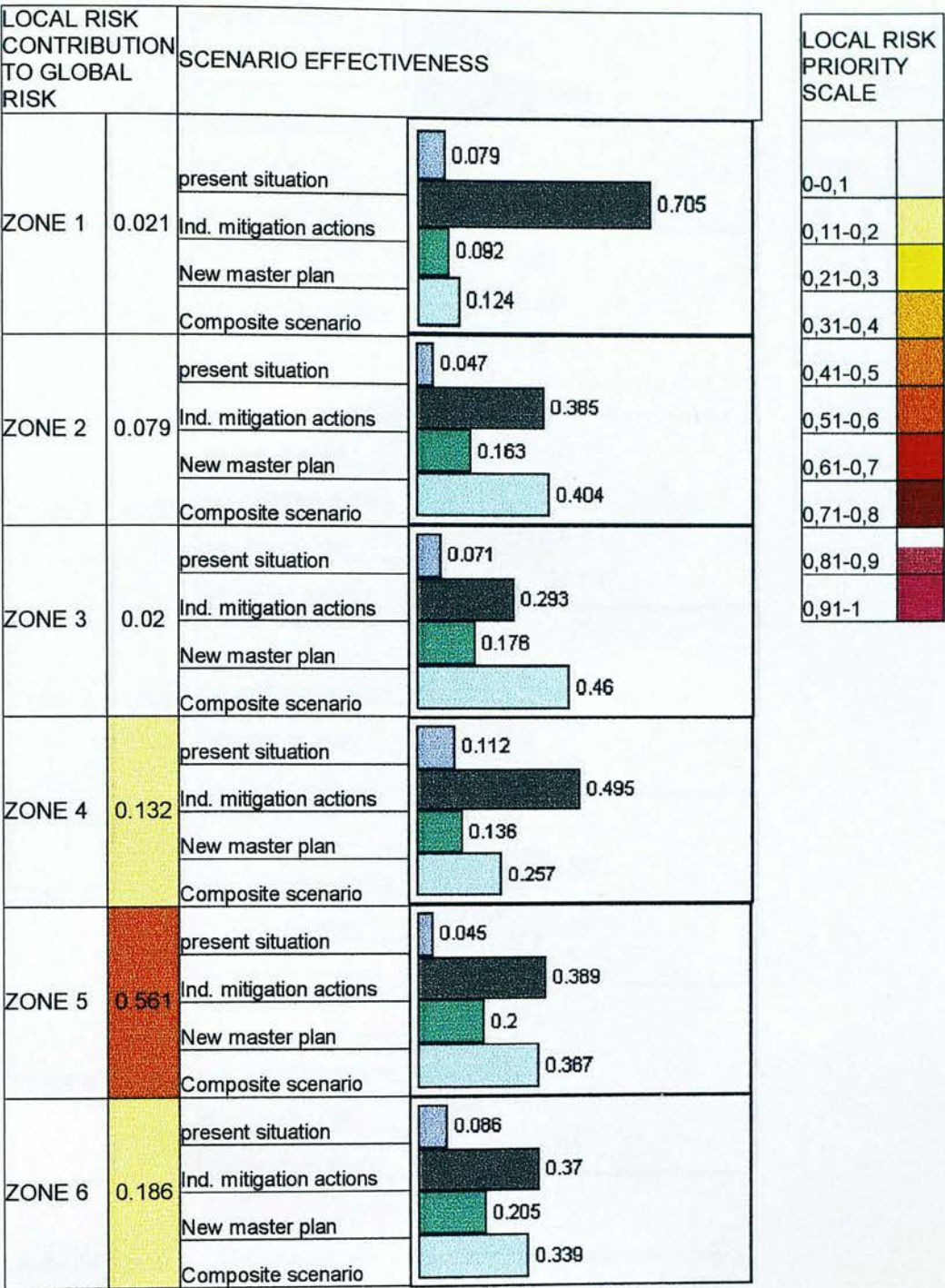
Regarding the quantitative results, they should be discussed in a group session, because numbers may reflect the general trend but not the single opinion. In this case, there is the genuine opportunity to input quantitative values, instead of verbal judgements, under the condition that everybody agrees on the indicators to be used.

More detailed conclusions can be made on the base of separate results, hierarchy and matrix. In the *APPENDIX C*, the coefficients of the aggregating equation on the base of the hierarchy analysis have been computed. These equations are of the type: $Y = x_1a_1 + x_2a_2 + \dots + x_na_n$ Where Y is the expected result, x and a are, respectively, the quantity of the scenario feature and the relative weight¹. Conceptually, the equations obtained by the hierarchy are very similar to those of the statistical regression and illustrate how flexible and useful are these partial results. In fact, by substituting the variables with the appropriate quantity of plants, transportation means and population, it is possible to obtain the overall risk rate (and safe measurements efficacy) of any possible scenario. However, at the time of writing, the quantification of each scenario is not available.

The purpose of this study is to control and reduce the risk of industrial accidents in Porto Marghera without considering any other factors (social, political, etc.) and goals, such as the general environmental control of the Venice territory. The reader must be aware that the alternatives may be assessed diversely under different conditions. However, a more rigorous approach, which takes into account all the environmental

¹ It must be noted that x variables are also affected by the preference level of each respondent. Since the questionnaire recorded these preferences, it is possible to compute the utility function of every indicator for each respondent. A wide explanation of them is in the next section.

matters and their pollution sources in a wider and general framework, is briefly presented in the next section.



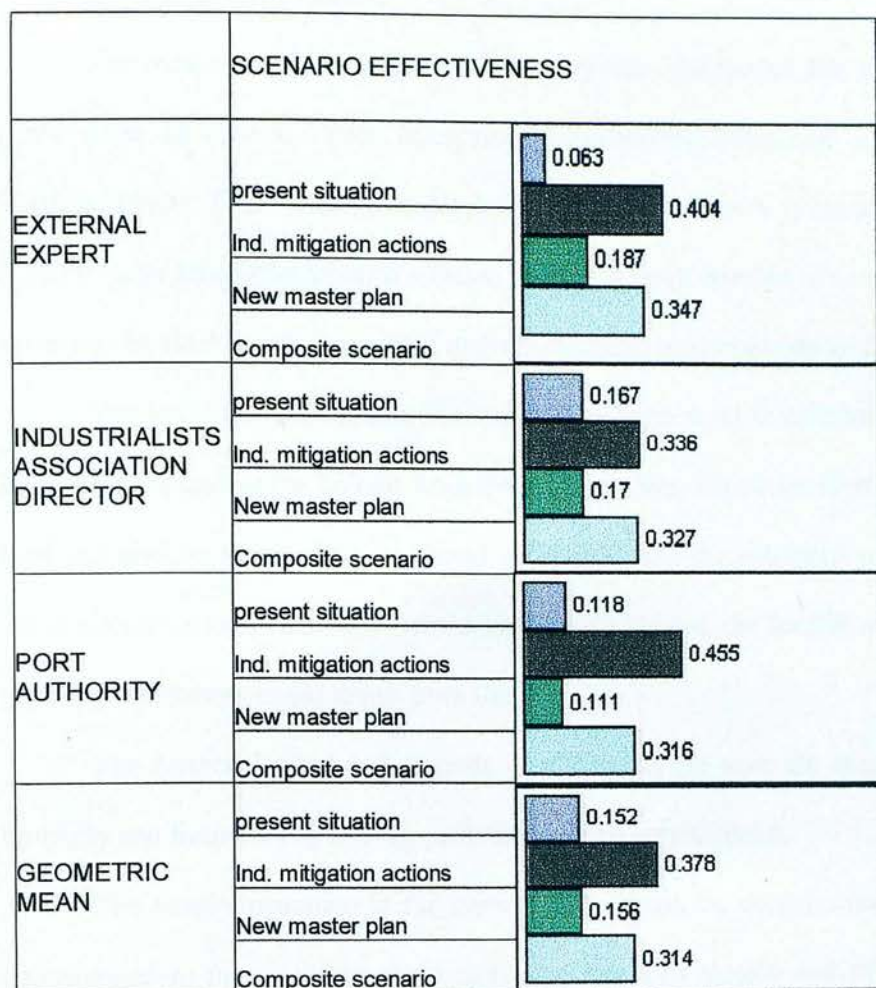
Tab. 13: external expert's evaluation resume

LOCAL RISK CONTRIBUTION TO GLOBAL RISK		SCENARIO EFFECTIVENESS		LOCAL RISK PRIORITY SCALE	
ZONE 1	0.059	present situation	0.194	0-0,1	
		Ind. mitigation actions	0.366	0,11-0,2	
		New master plan	0.185	0,21-0,3	
		Composite scenario	0.254	0,31-0,4	
ZONE 2	0.167	present situation	0.229	0,41-0,5	
		Ind. mitigation actions	0.296	0,51-0,6	
		New master plan	0.238	0,61-0,7	
		Composite scenario	0.238	0,71-0,8	
ZONE 3	0.025	present situation	0.051	0,81-0,9	
		Ind. mitigation actions	0.115	0,91-1	
		New master plan	0.417		
		Composite scenario	0.417		
ZONE 4	0.058	present situation	0.112		
		Ind. mitigation actions	0.167		
		New master plan	0.361		
		Composite scenario	0.361		
ZONE 5	0.461	present situation	0.155		
		Ind. mitigation actions	0.387		
		New master plan	0.098		
		Composite scenario	0.36		
ZONE 6	0.23	present situation	0.167		
		Ind. mitigation actions	0.321		
		New master plan	0.187		
		Composite scenario	0.324		

Tab. 14: Industrialists Association Director's evaluation resume

LOCAL RISK CONTRIBUTION TO GLOBAL RISK		SCENARIO EFFECTIVENESS		LOCAL RISK PRIORITY SCALE	
ZONE 1	0.167	present situation	0.139	0-0,1	
		Ind. mitigation actions	0.437	0,11-0,2	
		New master plan	0.126	0,21-0,3	
		Composite scenario	0.299	0,31-0,4	
ZONE 2	0.233	present situation	0.112	0,41-0,5	
		Ind. mitigation actions	0.46	0,51-0,6	
		New master plan	0.107	0,61-0,7	
		Composite scenario	0.321	0,71-0,8	
ZONE 3	0.067	present situation	0.107	0,81-0,9	
		Ind. mitigation actions	0.465	0,91-1	
		New master plan	0.1		
		Composite scenario	0.327		
ZONE 4	0.033	present situation	0.112		
		Ind. mitigation actions	0.46		
		New master plan	0.107		
		Composite scenario	0.321		
ZONE 5	0.3	present situation	0.112		
		Ind. mitigation actions	0.46		
		New master plan	0.107		
		Composite scenario	0.321		
ZONE 6	0.2	present situation	0.121		
		Ind. mitigation actions	0.452		
		New master plan	0.113		
		Composite scenario	0.314		

Tab. 15: Port Authority's evaluation resume



Tab. 16: scenario evaluation resume

7.6. A wider approach to Porto Marghera environment and its assessment

As already mentioned in chapter 4, the area of Porto Marghera suffers from many different problems, mainly due to its geographical location and its relationship with the Venice territory environment. According to the local experts (Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia, 1990), this environment can be described in terms of:

- the three main environmental components, namely water, land and air;

- its human and ecological characteristics;
- its built up environment.

The water-based or water-related ecosystem dominates the other components (Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia, 1990). This system is particularly complex because it is centred on a wide and shallow water basin (the lagoon) affected both by a large number of mainland fresh water flows and by tidal flows of seawater through the three lagoon entrances (I. Musu, 1998).

The land system embraces the mainland, a large number of islands and the coastal land-strips separating the lagoon from the Adriatic Sea. However, significant portions of land and shallow water were reclaimed as landfill sites for industrial waste disposals. In some circumstances, this waste could have contaminated the landfill and the leaking of polluting substances could result from this.

The meteorological and climatic conditions in the area are characterised by high humidity and frequent fog making pollution control very difficult.

The human presence in the area is high. It can be distinguished into: residents, concentrated in the most important residential areas of Venice and Mestre; a moderate number of workers mainly concentrated in Porto Marghera; a large influx of tourists in the Venice centre. The contribution of residents and workers to the environment depends on: their number, the energy consumption, amount of car ownership and car use, water use, the quality and treatment of their waste. Tourists may affect the solid waste production and the public transport use. Obviously, the most important human activities are concentrated in Porto Marghera (industries) and affect the environment by releasing pollutant into the lagoon and into the air directly or indirectly. In fact, some liquid and solid waste is incinerated and is replaced by atmospheric emissions. Fishing is also an important activity, which affects the lagoon ecosystem; in addition, about 60% of the total dry area is devoted to agriculture and breeding contributing to the degradation of the

environment. In particular, intensive agriculture may give rise to a high input of nutrients and of other substances into watercourses.

Finally, the built up environment is of a major international importance. It is most notably in the historic centre of Venice, but also in many of the others island around it. It is mainly threatened by the risk of flooding and air pollution damage. Another type of built environment is that in Porto Marghera, which has a high visual impact on the landscape: large oil tanks, pipelines and high chimneys (from 70 to 160 meters). Conversely, there are a number of existing or proposed nature protection areas within both the lagoon and the industrial estate.

In conclusion, the environment of the area where Porto Marghera is located is “(...) a very complex system with conflicting requirements being imposed upon it.” (Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia, 1990, page 32). Obviously, all these components contribute incrementally to the critical situation of the environmental quality of the area and most of them inter-act with each other at some point, making the ascertainment of the pollution sources very difficult, in particular those related to human activities. In addition, any non-detailed production and process changes of the activities in Porto Marghera “(...) have been accompanied by corresponding changes in the levels and composition of aqueous discharges, atmospheric emissions, noise, solid waste, risk of accident and visual impact associated with the zone. Ideally, to measure these for a full environmental compatibility study, we would need to establish the waste generating characteristics of all plants currently within the zone (...) and the characteristics of plants operating within the zone at earlier periods.” (Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia, 1990, page 25). However, this is virtually impossible as historical data is not often available and, when existing, records are fragmented and incomplete.

Nevertheless, the increase of public interest, both nationally and internationally, in environmental issues and the general concern regarding the environmental decline of the Venice territory, has encouraged some specialised investigations, which form the basis of the most important local environmental reports and studies (see, *inter alia*, Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia, 1990, and ARPAV, 2000). These investigations have identified the principal sources of pollution of the area allowing a recent procedure of pollution monitoring to be undertaken (ARPAV, 2000). The technical studies cover six main matters, strictly related to the elements describing the Venice territory environment (see the previous page): the lagoon; air quality; noise; waste; risk of accidents; landscape and visual quality.

The principal sources of waste inputs into the lagoon are:

- discharges of treated industrial effluents mainly from the Porto Marghera plants;
- discharges of cooling water again from Porto Marghera plants;
- maritime transport;
- discharges of treated domestic sewage;
- discharges of untreated domestic sewage from the historic city centre of Venice and that from other small island around it;
- pollutants, generated by inland domestic, agricultural and other industrial activities, which flow into the lagoon through waterways and run-off;
- accidental spillage into the lagoon;
- atmospheric pollution deposits;
- release of polluting substances from landfill areas (there are still seventeen uncontrolled dumps, which disperse pollutants mainly due to rain and tides).

The principal sources of atmospheric pollution are:

- industrial regular and accidental emissions;
- handicraft and commercial activities;

- domestic activities (i.e. heating, cooking, etc.);
- public, industrial and private transportation means;
- power production;
- incineration of liquid and solid waste;
- treatment of sludge and macro algae dredged from the lagoon (incineration).

Noise may arise from commercial as well as public and private transport. However, industrial activities in Porto Marghera carry the main responsibility for noise. In particular:

- process equipment, such as ovens, fans, motors, air and vapour vents and turbines;
- industrial transport, mainly composed by lorry traffic and tracks.

Solid and semi-solid waste may originate from a wide range of activities (industrial, handicraft and domestic). The Italian regulation classifies them into three main categories:

- urban solid waste;
- special waste, which cannot be assimilated with the urban solid types;
- toxic and harmful waste, which contains hazardous substances.

However, for the convenience of the environmental experts, they are grouped simply according to two principal sources: industrial and non-industrial.

The risk of accidents (which is the main subject of this research), derives mainly from industrial activities. It is assessed with regard to two main aspects:

- objective measurements (size of impact area, frequency of occurrence, etc.);
- subjective measurements (expert opinions, general public perceptions and concerns).

The industrial zone is also primarily responsible for the visual impact on landscape as it contains a considerable number of large dimension installations with unusual colours and shapes. In particular, the chimneys are very tall (the tallest is 160 m. high), due to

safety measures, and present alternating red and white bands at their top (because of the air traffic regulation); in addition, their emissions are visually unpleasant. An industrial development like this is inevitably visible from a long distance, including the historical centre of Venice.

There are other events resulting in significant impacts to the natural and built up environment, which are not directly attributable to the activities of Porto Marghera. They are:

- a civil transport disaster (in reality, very rare);
- an accidental release of toxic substances in one of the watercourses flowing into the lagoon;
- abnormally high tides (very frequent), which damage the historical buildings in Venice and accelerate the uncontrolled pollutant dispersion from the landfill sites.

In addition, they contribute to turn the lagoon into a sea environment, destroying the original ecosystem.

Flooding is a very complex problem, caused by two correlated phenomena:

- subsidence: a lowering of the ground level mainly due to the exploitation of underground water resources for industrial purposes;
- eustasy: a change of sea level (raising) due to changes in the world's climate.

Until few years ago, flooding was mainly caused by subsidence (13 centimetres in 88 years); however, severe controls on industrial water uses and general building consolidations have sensibly reduced it. Conversely, eustasy is now primarily responsible for most of the abnormally high tides (1.27 mm per year).

The "Rapporto Ambientale d'Area della Zona Industriale di Porto Marghera" (the 'Environmental Report on Industrial estate of Porto Marghera'), ARPAV (2000), clarifies and illustrates these pollution sources in general and the environmental compatibility² of

² Environmental compatibility is defined as the quality achieved when "(...) the activities (industrial, civil, etc.) of one area are undertaken in ways which are consistent with the attainment of the environmental goals

the industrial activities within the territory of Venice in detail. In accordance with the previous specialised studies³, it covers all types of industrial activities with respect to all elements of the environments in a framework model known as 'Pressure-State-Response' (PSR). This model, first conceived by the *Organisation for Economic Co-operation and Development* (OECD), is simply based on the idea that any human activity exerts pressure on the environment, which can generate changes in the state of the environment. As a consequence, society responds to this change with environmental and economic policies and programs to prevent, reduce or mitigate pressures and environmental damage. An example in the pressure-state-response framework can be the following. An environmental agency, which monitors the level of pollutants in the air, verifies an elevated level of pollutant. Therefore, it responds to that level of pollution by limiting the pollution sources (e.g. issuing permits to the facilities responsible for it).

The study of Porto Marghera estate and its surrounding ("state"), the analysis of Major Industrial Hazards ("pressure"), the General Agreement on Chemical Hazard Mitigation Actions and the New Master Plan ("response") compose the specialised study of the 'risk of accidents' carried out by the Italian Environmental Protection Agency in Porto Marghera. The experimental model measures the efficacy of the responses relative to the "pressure", taking into account the "state" and its complexity. However, the experimental procedure for risk assessing is just one aspect of this environment and, clearly, the impact of the Industrial Zone should be more meaningfully examined within the above mentioned global context. A more rigorous procedure should take into account

for that area." (*Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia*, 1990, page VII). It is slightly different from 'sustainability', which is a more general principle. In fact, it is a quality of any development that (...) meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development (WCED). *Our common future*. Oxford: Oxford University Press, 1987 p. 43).

³ I refer in particular to the already mentioned *Ente Zona Industriale Porto Marghera, Associazione Industriali della Provincia di Venezia* (1990), as it is a preliminary study, which "(...) assembled and analysed a large amount of data within the comprehensive framework required for an environmental compatibility study." (page VII).

all the environmental matters and their pollution sources in a wider and general framework such as the one shown in figure 62.

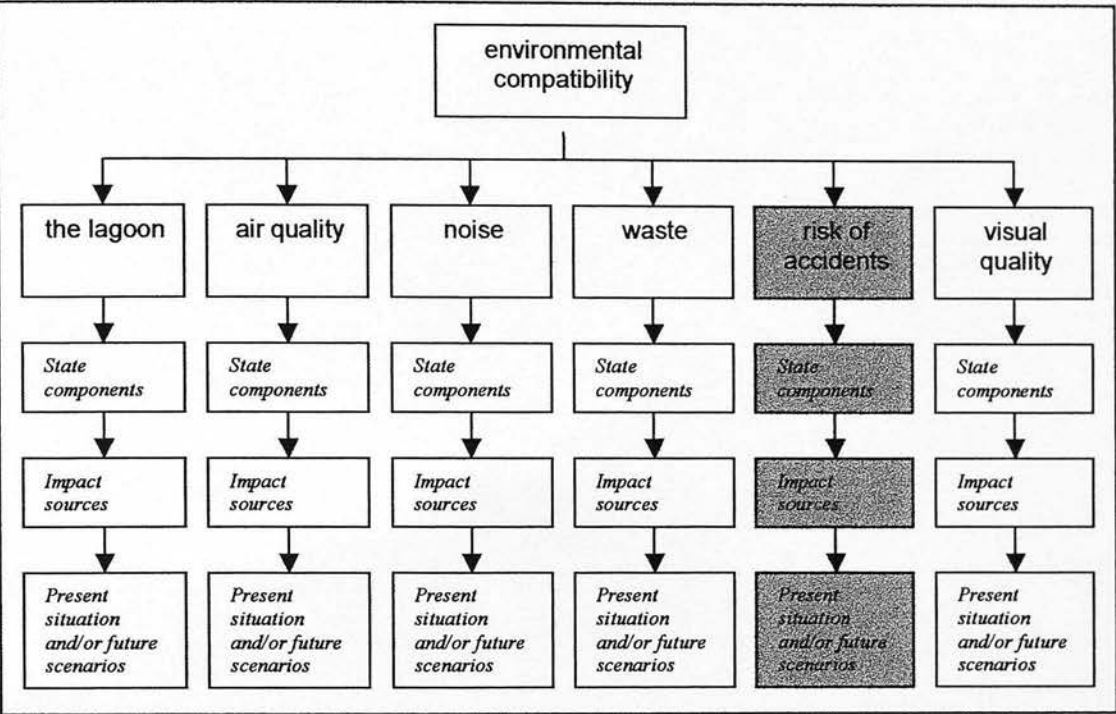


Figure 62: a general hierarchy for measuring the global environmental compatibility of Venice territory (the grey cells corresponds to the matters analysed in this work)

In this, every environmental matter can be analysed by using the AHP method. All the state components are ordered in a hierarchy wherein the relative importance of each is determined through the pair-wise comparison technique and the impact of each pollution source is estimated. Then, the priorities are aggregated in one unique score, which measures the importance of the relative matter. By super-imposing a general hierarchy, it is possible to relate all the environmental matters and estimate the reciprocal importance, so that the AHP aggregation of each score will provide a measure of environmental compatibility of the area regard to all the state components, human activities and pollution sources, in the present as well as in the future.